CHAPTER VI.

THE STEAM-ENGINE OF TO-DAY.

. . . "AND, last of all, with inimitable power, and 'with whirlwind sound,' comes the potent agency of steam. In comparison with the past, what centuries of improvement has this single agent comprised in the short compass of fifty years! Everywhere practicable, everywhere efficient, it has an arm a thousand times stronger than that of Hercules, and to which human ingenuity is capable of fitting a thousand times as many hands as belonged to Briareus. Steam is found in triumphant operation on the seas; and, under the influence of its strong propulsion, the gallant ship—

'Against the wind, against the tide,
Still steadies with an upright keel.'

It is on the rivers, and the boatman may repose on his oars; it is on highways, and exerts itself along the courses of land-conveyance; it is at the bottom of mines, a thousand feet below the earth's surface; it is in the mills, and in the workshops of the trades. It rows, it pumps, it excavates, it carries, it draws, it lifts, it hammers, it spins, it weaves, it prints. It seems to say to men, at least to the class of artisans: 'Leave off your manual labor; give over your bodily toil; bestow but your skill and reason to the directing of my power, and I will bear the toil, with no muscle to grow weary, no nerve to relax, no breast to feel faintness!' What further improvement may still be made in the use of this astonishing power it is impossible to know, and it were vain to conjecture. What we do know is, that it has most essentially altered the face of affairs, and that no visible limit yet appears beyond which its progress is seen to be impossible."—DANIEL WEBSTER.

THE PERIOD OF REFINEMENT—1850 TO DATE.

BY the middle of the present century, as we have now seen, the steam-engine had been applied, and successfully, to every great purpose for which it was fitted. Its first application was to the elevation of water; it next was applied to the driving of mills and machinery; and it finally became the great propelling power in transportation by land and by sea.

At the beginning of the period to which we are now come, these applications of steam-power had become familiar both to the engineer and to the public. The forms of engine adapted to each purpose had been determined, and had become usually standard. Every type of the modern steam-engine had assumed, more or less closely, the form and proportions which are now familiar; and the most intelligent designers and builders had been taught—by experience rather than by theory, for the theory of the steam-engine had then been but little investigated, and the principles and laws of thermodynamics had not been traced in their application to this engine—the principles of construction essential to successful practice, and were gradually learning the relative standing of the many forms of steam-engine, from among which have been preserved a few specially fitted for certain specific methods of utilization of power.

During the years succeeding the date 1850, therefore, the growth of the steam-engine had been, not a change of standard type, or the addition of new parts, but a gradual improvement in forms, proportions, and arrangements of details; and this period has been marked by the dying out of the forms of engine least fitted to succeed in competition with others, and the retention of the latter has been an example of "the survival of the fittest." This has therefore been a Period of Refinement.

During this period invention has been confined to details; it has produced new forms of parts, new arrangements of details; it has devised an immense variety of valves, valve-motions, regulating apparatus, and a still greater variety of steam-boilers and of attachments, essential and non-essential, to both engines and boilers. The great majority of these peculiar devices have been of no value, and very many of the best of them have been found to have about equal value. All the well-known and successful forms of engine, when equally well designed and constructed and equally well managed, are of very nearly equal efficiency; all of the best-known types of steam-boiler, where given equal proportions of grate to heating-surface and equally well designed, with a view to securing a good draught and a good circulation of water, have been found to give very nearly equally good results; and it has become evident that a good knowledge of principles and of practice, on the part of the designer, the constructor, and the manager of the boiler, is essential in the endeavor to achieve economical success; that good engineering is demanded, rather than great ingenuity. The inventor has been superseded here by the engineer.

The knowledge acquired in the time of Watt, of the essential principles of steam-engine construction, has since become generally familiar to the better class of engineers. It has led to the selection of simple, strong, and durable forms of engine and boiler, to the introduction of various kinds of valves and of valve-gearing, capable of adjustment to any desired range of expansive working, and to the attachment of efficient forms of governor to regnlate the speed of the engine, by determining automatically the point of cut-off which will, at any instant, best adjust the energy exerted by the expanding steam to the demand made by the work to be done.

The value of high pressures and considerable expansion was recognized as long ago as in the early part of the present century, and Watt, by combining skillfully the several principal parts of the steam-engine, gave it very nearly the shape which it has to-day. The compound engine, even, as has been seen, was invented by contemporaries of Watt, and the only important modifications since his time have occurred in details. The introduction of the "drop cut-off," the attachment of the governor to the expansion-apparatus in such a manner as to determine the degree of expansion, the improvement of proportions, the introduction of higher steam and greater expansion, the improvement of the marine engine by the adoption of surface-condensation, in addition to these other changes, and the introduction of the double-cylinder engine, after the elevation of steam-pressure and increase of expansion had gone so far as to justify its use, are the changes, therefore, which have taken place during this last quarter-century. It began then to be generally understood that expansion of steam produced economy, and mechanics and inventors vied with each other in the effort to obtain a form of valve-gear which should secure the immense saving which an abstract consideration of the expansion of gases according to Marriotte's law would seem to promise. The counteracting phenomena of internal condensation and reëvaporation, of the losses of heat externally and internally, and of the effect of defective vacuum, defective distribution of steam, and of back-pressure, were either unobserved or were entirely overlooked.

It was many years, therefore, before engine-builders became convinced that no improvement upon existing forms of expansion-gear could secure even an approximation to theoretical efficiency.

The fact thus learned, that the benefit of expansive working has a limit which is very soon reached in ordinary practice, was not then, and has only recently become, generally known among our steam-engine builders, and for several years, during the period upon which we now enter, there continued the keenest competition between makers of rival forms of expansion-gear, and inventors were continually endeavoring to produce something which should far excel any previously-existing device.

In Europe, as in the United States, efforts to "improve" standard designs have usually resulted in injuring their efficiency, and in simply adding to the first cost and running expense of the engines, without securing a marked increase in economy in the consumption of steam.

Section I.—Stationary Engines.

"Stationary Engines" had been applied to the operation of mill-machinery, as has been seen, by Watt and by Murdoch, his assistant and pupil; and Watt's competitors, in Great Britain and abroad, had made considerable progress before the death of the great engineer, in its adaptation to its work. In the United States, Oliver Evans had introduced the non-condensing high-pressure stationary engine, which was the progenitor of the standard engine of that type which is now used far more generally than any other form. These engines were at first rude in design, badly proportioned, rough and inaccurate as to workmanship, and uneconomical in their consumption of fuel. Gradually, however, when made by reputable builders, they assumed neat and strong shapes, good proportions, and were well made and of excellent materials, doing their work with comparatively little waste of heat or of fuel.

One of the neatest and best modern designs of stationary engine for small powers is seen in Fig. 93, which represents a "vertical direct-acting engine," with base-plate—a form which is a favorite with many engineers.

The engine shown in the engraving consists of two principal parts, the cylinder and the frame, which is a tapering column having openings in the sides, to allow free access to all the working parts within. The slides and pillow-blocks are cast with the column, so that they cannot become loose or out of line; the rubbing surfaces are large and easily lubricated. Owing to the vertical position, there is no tendency to side wear of cylinder or piston. The packing-rings are self-adjusting, and work free but tight. The crank is counterbalanced; the crank-pin, cross-head pin, piston-rod, valve-stem, etc., are made of steel; all the bearing surfaces are made extra large, and are accurately fitted; and the best quality of Babbitt-metal only used for the journal-bearings.

The smaller sizes of these engines, from 2 to 10 horse-power, have both pillow-blocks cast in the frame, giving a

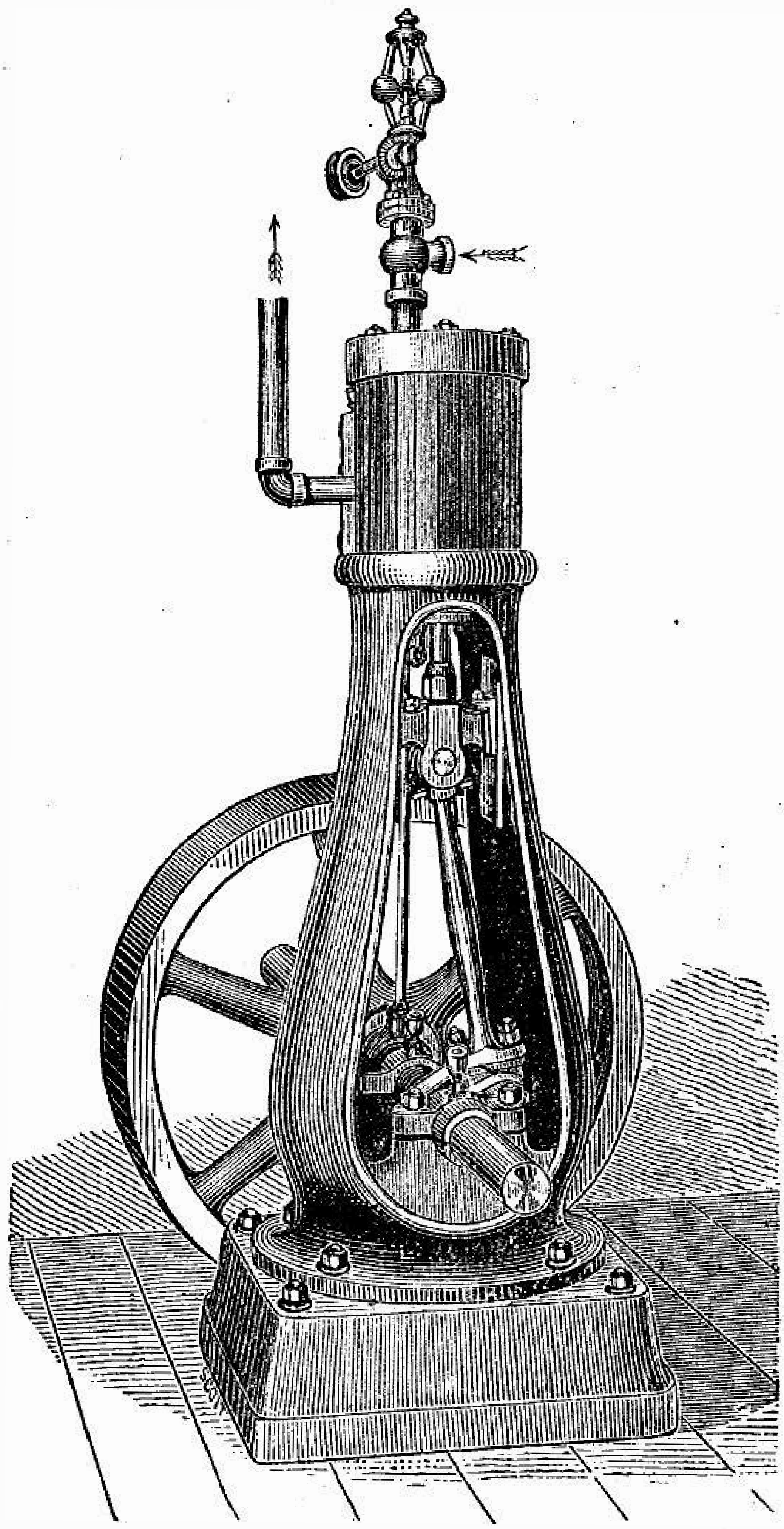


FIG. 93.—Vertical Stationary Steam-Engine.

bearing each side of the double cranks. They are built by some constructors in quantities, and parts duplicated by special machinery (as in fire-arms and sewing-machines), which secures great accuracy and uniformity of workmanship, and allows of any part being quickly and cheaply replaced, when worn or broken by accident. The next figure is a vertical section through the ~~same~~ engine.

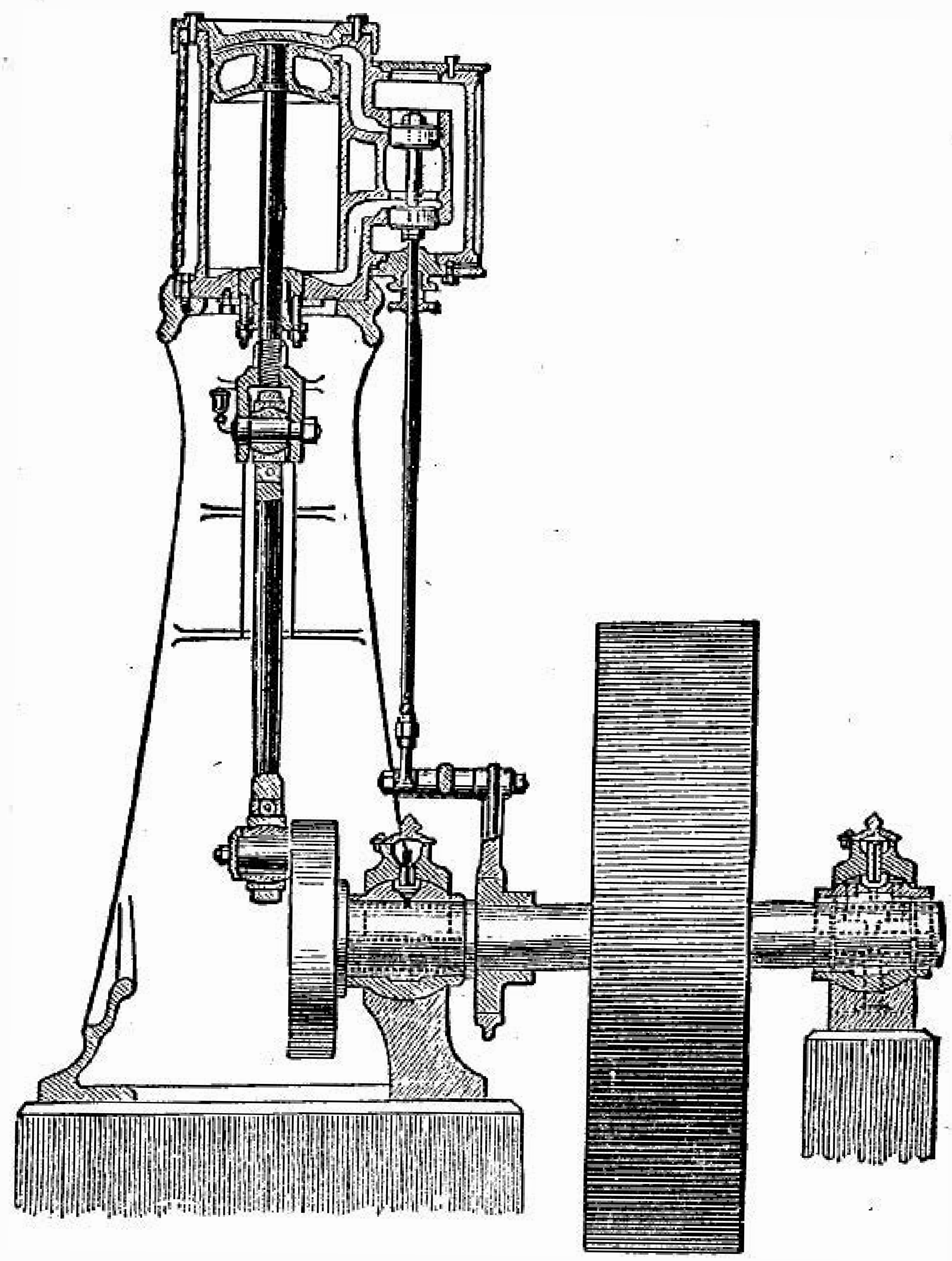


Fig. 94.—Vertical Stationary Steam-Engine. Section.

Engines fitted with the ordinary rigid bearings require to be erected on a firm foundation, and to be kept in perfect line. If, by the settling of the foundation, or from any other cause, they get out of line, heating, cutting, and thumping result. To obviate this, modern engines are often fitted with self-adjusting bearings throughout; this gives the engine great flexibility and freedom from friction. The accompanying cuts show clearly how this is accomplished.

The pillow-block has a spherical shell turned and fitted into the spherically-bored pillow-block, thus allowing a slight angular motion in any direction. The connecting-rod is forged in a single piece, without straps, gibs, or key, and is mortised through at each end for the reception of the brass boxes, which are curved on their backs, and fit the check-pieces, between which they can turn to adjust themselves to the pins, in the plane of the axis of the rod. The adjustment for wear is made by wedge-blocks and set screws, as shown, and they are so constructed that the parts cannot get loose and cause a break-down. The cross-head has adjustable gibs on each side, turned to fit the slides, which are cast solidly in the frame, and bored out exactly in the line with the cylinder. This permits it freely to turn on its axis, and, in connection with the adjustable boxes in the connecting-rod, allows a perfect self-adjustment to the line of the crank-pin. The out-board bearing may be moved an inch or more out of position in any direction, without detriment to the running of the engine, all bearings accommodating themselves perfectly to whatever position the shaft may assume.

The ports and valve-passages are proportioned as in locomotive practice. The valve-seat is adapted to the ordinary plain slide or D-valve, should it be preferred, but the balanced piston slide-valve works with equal ease whether the steam-pressure is 10 or 100 pounds, and at the same time gives double steam and exhaust openings, which greatly facilitates the entrance of the steam to, and its escape from, the cylinder, thus securing a nearer approach to boiler-pressure and a less back-pressure, saving the power required to work an ordinary valve, and reducing the wear of valve-gear.

This is a type of engine frequently seen in the United States, but more rarely in Europe. It is an excellent form of engine. The vertical direct-acting engine is sometimes, though rarely, built of very considerable size, and these large engines are more frequently seen in rolling-mills than elsewhere.

Where much power is required, the stationary engine is usually an horizontal direct-acting engine, having a more or less effective cut-off valve-gear, according to the size of engine and the cost of fuel. A good example of the simpler form of this kind of engine is the small horizontal slide-valve engine, with independent cut-off valve riding on the back of the main valve—a combination generally known among engineers as the Meyer system of valve-gear. This form of steam-engine is a very effective machine, and does excellent work when properly proportioned to yield the required amount of power. It is well adapted to an expansion of from four to five times. Its disadvantages are the difficulty which it presents in the attachment of the regulator, to determine the point of cut-off by the heavy work which it throws upon the governor when attached, and the rather inflexible character of the device as an expansive valve-gear. The best examples of this class of engine have neat heavy bed-plates, well-designed cylinders and details, smooth-working valve-gear, the expansion-valve adjusted by a right and left hand screw, and regulation secured by the attachment of the governor to the throttle-valve.

The engine shown in the accompanying illustration (Fig. 95) is an example of an excellent British stationary steam-engine. It is simple, strong, and efficient. The frame, front cylinder-bead, cross-head guides, and crank-shaft "plumber-block," are cast in one piece, as has so generally been done in the United States for a long time by some of our manufacturers. The cylinder isnsecured against the end of the bed-plate, as was first done by Corliss. The crank-pin is set in a counterbalanced disk. The valve-gear is simple, and the governor effective, and provided with a safety-device to prevent injury by the breaking of the governor-belt. An engine of this kind of 10 inches diameter of cylinder, 20 inches stroke of piston, is rated by the builders at about 25 horse-power; a similar engine 30 inches in diameter of cylinder would yield from

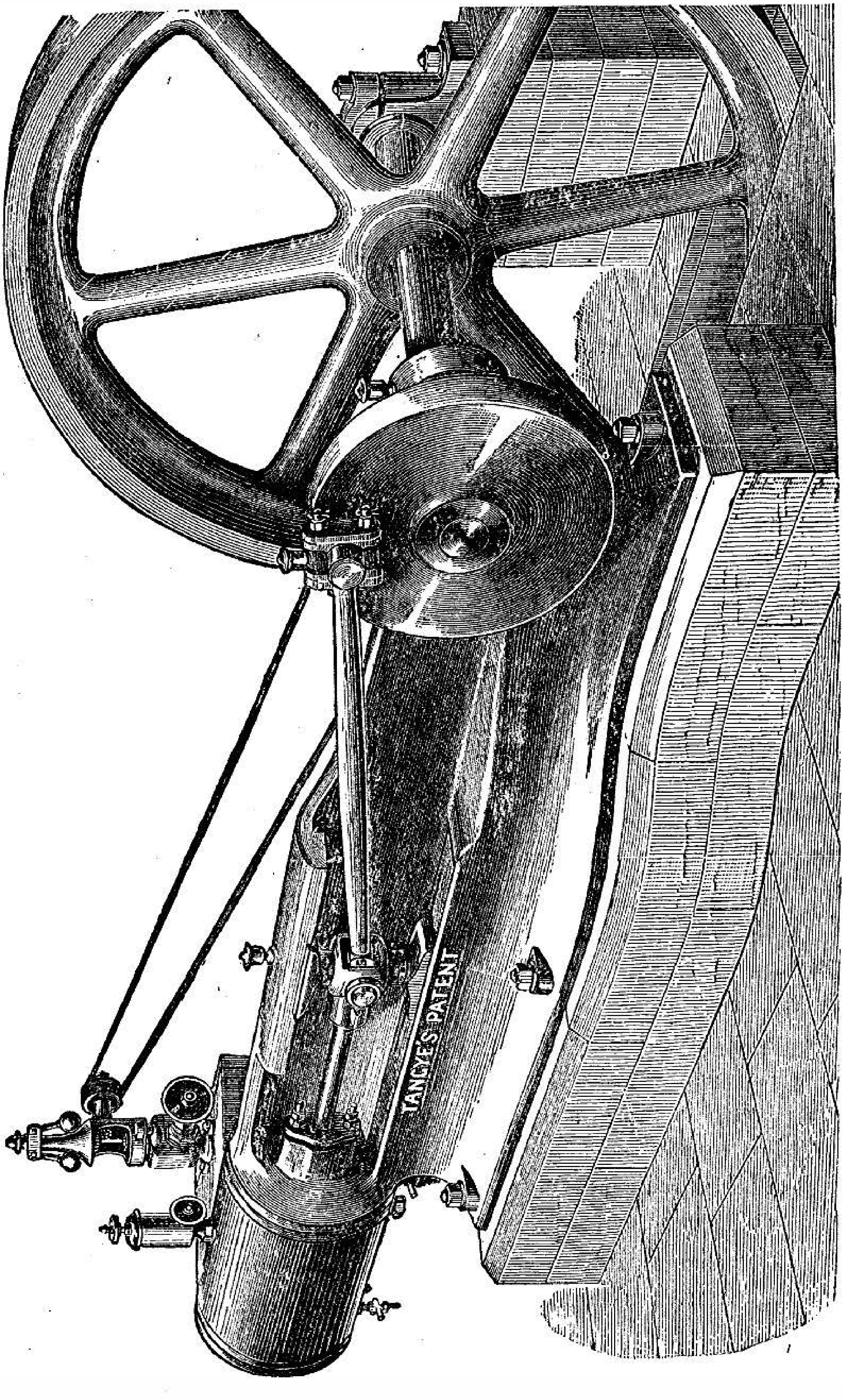


FIG. 93.—Horizontal Stationary Steam-Engine.

225 to 250 horse-power. In this example, all parts are made to exact size by gauges standardized to Whitworth's sizes.

In American engines (as is seen in Fig. 96), usually, two supports are placed—the one under the latter bearing, and

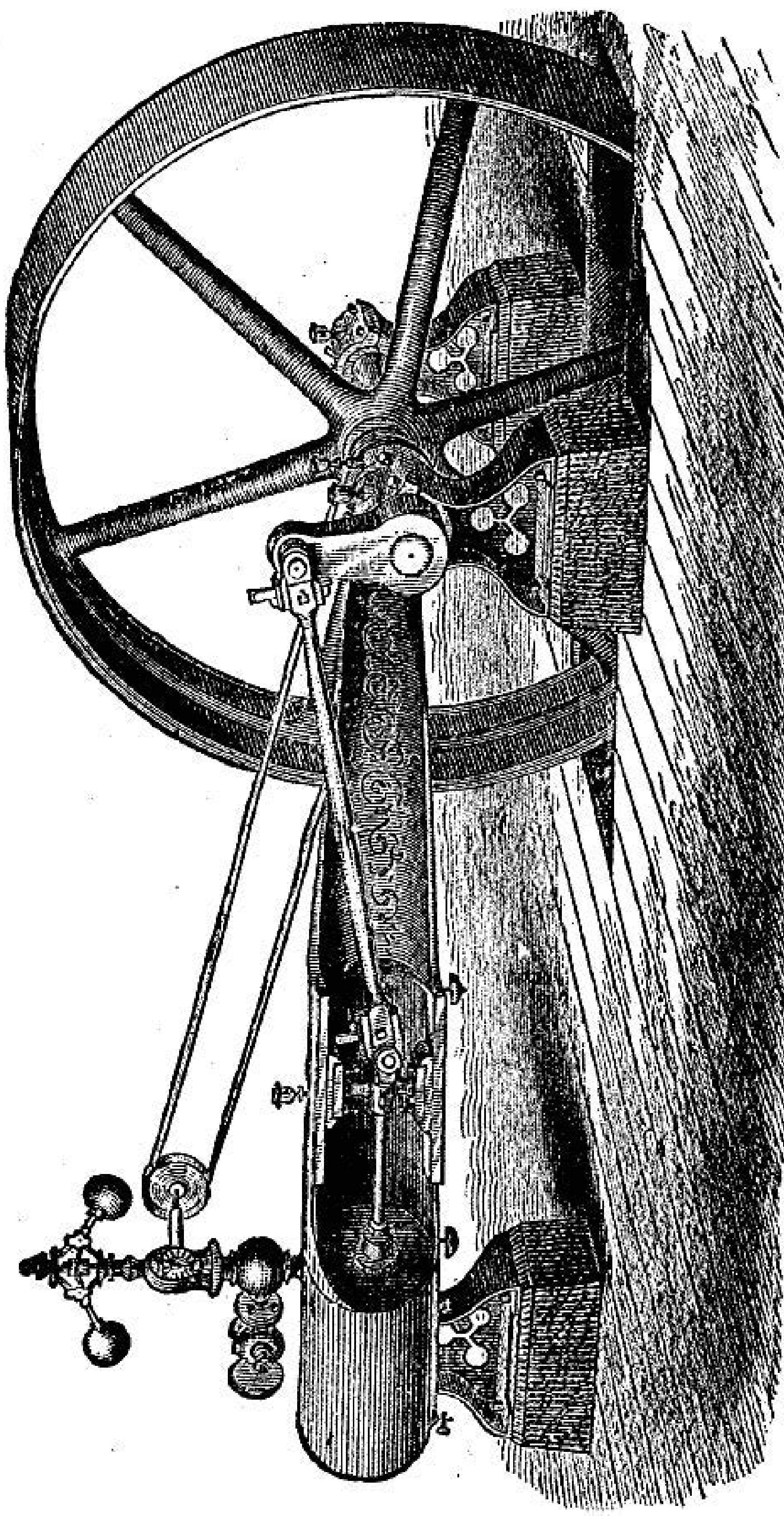


FIG. 96.—Horizontal Stationary Steam-Engine.

the other under the cylinder—to take the weight of the engine; and through them it is secured to the foundation. As in the vertical engine already described, a valve is sometimes used, consisting of two pistons connected by a rod, and worked by an ordinary eccentric. By a simple arrangement these pistons have always the same pressure inside as out, which prevents any leakage or blowing through; and they are said always to work equally as well and free from friction under 150 pounds pressure as under 10 pounds per square inch, and to require no adjustment. It is more usual, however, to adopt the three-ported valve used on locomotives, with (frequently) a cut-off valve on the back of this main valve, which cut-off valve is adjusted either by hand or by the governor.

Engines of the class just described are especially well fitted, by their simplicity, compactness, and solidity, to work at the high piston-speeds which are gradually becoming generally adopted in the effort to attain increased economy of fuel by the reduction of the immense losses of heat which occur in the expansion of steam in the metallic cylinders through which we are now compelled to work it.

One of the best known engines is the Porter-Allen engine, a steam-engine having the same general arrangement of parts seen in the above illustration, but fitted with a peculiar valve-gear, and having proportions of parts which are especially calculated to secure smoothness of motion and uniformity of pressure on crank-pin and journals, at speeds so high that the inertia of the reciprocating parts becomes a seriously-important element in the calculation of the distribution of stresses and their effect on the dynamics of the machine.

The Porter-Allen[1] cylinder and frame are connected as in the engine seen above, and the crank-disk, shaft-bearings, and other principal details, are not essentially different. The valve-gear[2] differs in having four valves, one at each end on the steam as well as on the exhaust side, allaof which are balanced and work with very little resistance. These valves are not detachable, but are driven by

[1] The invention of Messrs. Charles T. Porter and John F. Allen.
[2] Invented by Mr. John F. Allen.

a link attached to and moved by an eccentric on the main shaft, the positionnof the valve-rod attachment to which link is determined by the governor, and the degree of expansion is thus adjusted to the work of the engine. The engine has usually a short stroke, not exceeding twice the diameter of cylinder, and is driven at very high speed, generally averaging from 600 to 800 feet per minute.[1] This high piston-speed and short stroke give very great velocity of rotation. The effect is, therefore, to produce an exceptional smoothness of motion, while permitting the use of small fly-wheels. Its short stroke enables entire solidity to be attained in a bed of rigid form, making it a very completely self-contained engine, adapted to the heaviest work, and requiring only a small foundation.

The journals of the shaft, and all cylindrical wearing surfaces, are finished by grinding in a manner that leaves them perfectly round. The crank-pin and cross-head pin are hardened before being ground. The joints of the valve-gear consist of pins turning in solid ferrules in the rod-ends, both hardened and ground. After years of constant use thus, no wear occasioning lost time in the valve-movements has been detected.

High speed and short strokes are essential elements of economy. It is now well understood that all the surfaces with which the steam comes in contact condense it.

Obviously, one way to diminish this loss is to reduce the extent of surface to which the steam is exposed. In engines of high speed and short stroke, the surfaces with which the steam comes in contact, while doing a given amount of work, present less area than in ordinary engines running at low speed. Where great steadiness of motion is desired, the expense of coupled engines is often incurred. Quick-running engines do not require to be coupled; a single engine may give greater uniformity of motion than is usu-

[1] Or not far from 600 times the cube root of the length of stroke, measured in feet.

ally obtained with coupled engines at ordinary speeds. The ports and valve-movements, the weight of the reciprocating parts, and the size and weight of the fly-wheels, should be calculated expressly for the speeds chosen.

The economy of the engine here described is unexcelled by the best of the more familiar "drop cut-off" engines.

An engine reported upon by a committee of the American Institute, of which Dr. Barnard was chairman, was non-condensing, 16 inches in diameter of cylinder, 30 inches stroke, making 125 revolutions per minute, and developed over 125 horse-power with 75 pounds of steam in the boiler, using 25¾ pounds of steam per indicated horse-power, and 2.87 pounds of coal—an extraordinarily good performance for an engine of such small power.

The governor used on this engine is known as the Porter governor. It is given great power and delicacy by weighting it down, and thus obtaining a high velocity of rotation, and by suspending the balls from forked arms, which are given each two bearing-pins separated laterally so far as to permit considerable force to benexerted in changing speeds without cramping those bearings sufficiently to seriously impair the sensitiveness of the governor. This engine as a whole may be regarded as a good representative of the high-speed engine of to-day.

Since this change in the direction of high speeds has already gone so far that the "drop cut-off" is sometimes inapplicable, in consequence of the fact that the piston would, were such a valve-gear adopted, reach the end of its stroke before the detached valve could reach its seat; and since this progress is only limited by our attainments in mechanical skill and accuracy, it seems probable that the "positive-motion expansion-gear" type of engine will ultimately supersede the now standard "drop cut-off engine."

The best known and most generally used class of stationary engines at the present time is, however, that which has the so-called "drop cut-off," or "detachable valve-gear." The oldest well-known form of valve-motion of this description now in use is that known as the Sickels cut-off, patented by Frederick E. Sickels, an American mechanic, about the year 1841, and also built by Hogg, of New York, who placed it upon the engine of the steamer South America. The invention is claimed for both Hogg and Sickels. It was introduced by the inventor in a form which especially adapted it to use with the beam-engine used on the Eastern waters of the United States, and was adapted to stationary engines by Messrs. Thurston, Greene & Co., of Providence, R. I., who made use of it for some years before any other form of "drop cut-off" came into general use. The Sickels cut-off consisted of a set of steam-valves, usually independent of the exhaust-valves, and each raised by a catch, which could be thrown out, at the proper moment, by a wedge with which it came in contact as it rose with the opening valve. This wedge, or other equivalent device, was so adjusted that the valve should be detached and fall to its seat when the piston reached that point in its movement, after taking steam, at which expansion was to commence. From this point, no steam entering the cylinder, the piston was impelled by the expanding vapor. The valve was usually the double-poppet. Sickels subsequently invented what was called the "beam-motion," to detach the valve at any point in the stroke. As at first arranged, the valve could only be detached during the earlier half-stroke, since at mid-stroke the direction of motion of the eccentric rod wasn reversed and the valve began to descend. By introducing a "wiper" having a motion transverse to that of the valve and its catch, and by giving this wiper a motion coincident with that of the piston by connecting it with the beam or other part of the engine moving with the piston, he obtained a kinematic combination which permitted the valve to be detached at any point in the stroke, adding a very simple contrivance which enabled the attendant to set the wiper so that it should strike the catch at any time during the forward movement of the "beam-motion."

On stationary engines, the point of cut-off was afterward determined by the governor, which was made to operate the detaching mechanism, the combination forming what is sometimes called an "automatic" cut-off. The attachment of the governor so as to determine the degree of expansion had been proposed before Sickels's time. One of the earliest of these contrivances was that of Zachariah Allen, in 1834, using a cut-off valve independent of the steam-valve. The first to so attach the governor to a *drop cut-off* valve-motion was George H. Corliss, who made it a feature of the Corliss valve-gear in 1849. In the year 1855, N. T. Greene introduced a form of expansion-gear, in which he combined the range of the Sickels beam-motion device with the expansion-adjustment gained by the attachment of the governor, and with the advantages of flat slide-valves at all ports—both steam and exhaust.

Many other ingenious forms of expansion valve-gear have been invented, and several have been introduced, which, properly designed and proportioned to well-planned engines, and with good construction and management, should give economical results little if at all inferior to those just named. Among the most ingenious of these later devices is that of Babcock & Wilcox, in which a very small auxiliary steam-cylinder and piston is employed to throw the cut-off valve over its port at the instant at which the steam is to be cut off. A very beautiful form of isochronous governor is used on this engine, to regulate the speed of the engine by determining the point of cut-off.

In Wright's engine, the expansion is adjusted by the movement, by the regulator, of cams which operate the steam-valves so that they shall hold the valve open a longer or shorter time, as required.

Since compactness and lightness are not as essential as in portable, locomotive, and marine engines, the parts are arranged, in stationary engines, with a view simply to securing efficiency, and the design is determined by circumstances. It was formerly usual to adopt the condensing engine in mills, and wherever a stationary engine was required. In Europe generally, and to some extent in the United States, where a supply of condensing water is obtainable, condensing engines and moderate steam-pressures are still employed. But this type of engine is gradually becoming superseded by the high-pressure condensing engine, with considerable expansion, and with an expansion-gear in which the point of cut-off is determined by the governor.

The best-known engine of this class is the Corliss engine, which is very extensively used in the United States, and which has been copied very generally by European builders. Fig. 97 represents the Corliss engine. The

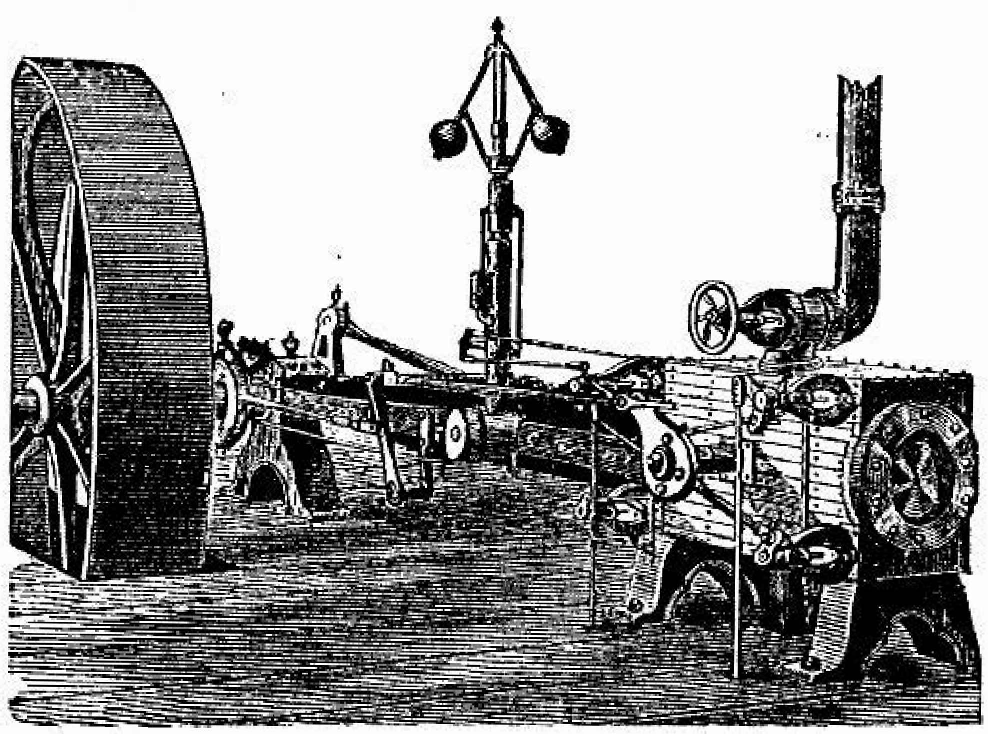


Fig. 97.—Corliss Engine.

horizontal steam-cylinder is bolted firmly to the end of the frame, which is so formed as to transmit the strain to the main journal with the greatest directness. The frame carries the guides for the cross-head, which are both in the same vertical plane. The valves are four in number, a steam and an exhaust valve being placed at each end of the steam-cylinder. Short steam-passages are thus secured, and this diminution of clearance is a source of some economy. Both sets of valves are driven by an eccentric operating a disk or wrist-plate, *E* (Fig. 98), which vibrates on a pin projecting from the cylinder. Short links reaching from this wrist-plate to the several valves, *D D*, *F F*, move them with

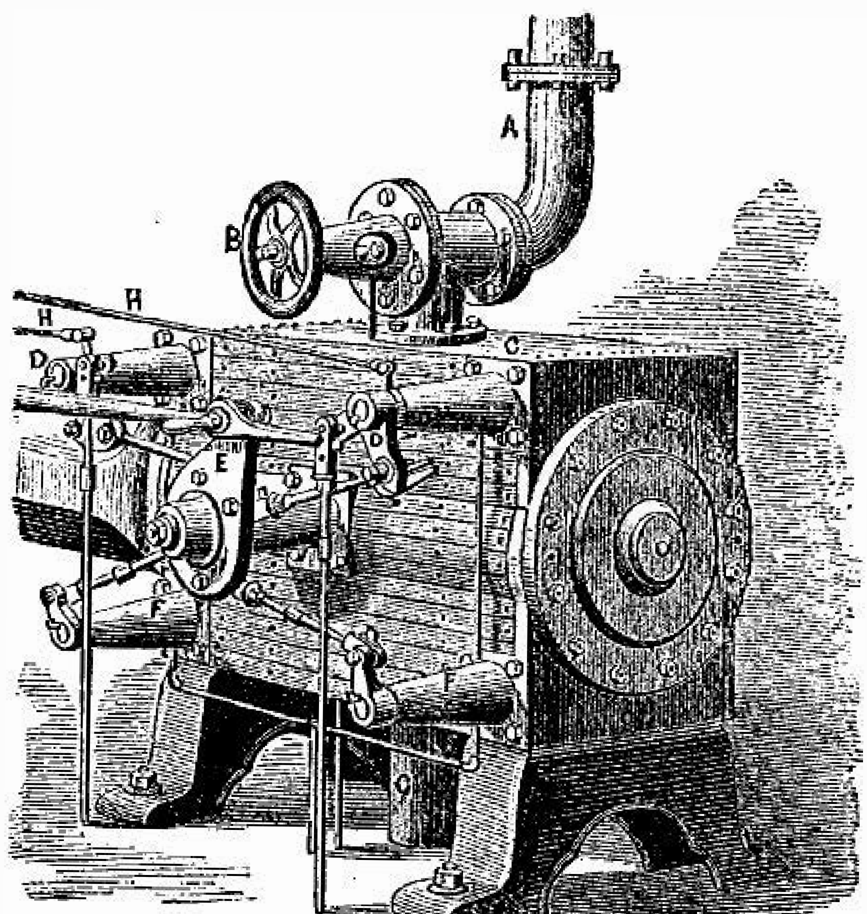


FIG. 98.—Corliss Engine Valve-Motion.

a peculiarly varying motion, opening and closing them rapidly, and moving them quite slowly when the port is either nearly open or almost closed. This effect is ingeniously secured by so placing the pins on the wrist-plate that their line of motion becomes nearly transverse to the direction of the valve-links when the limit of movement is approached. The links connecting the wrist-plate with the arms moving the steam-valves have catches at their extremities, which are disengaged by coming in contact, as the arm swings around with the valve-stem, with a cam adjusted by the governor. This adjustment permits the steam to follow the piston farther when the engine is caused to "slow down," and thus tends to restore the proper speed. It disengages the steam-valve earlier, and expands the steam to a greater extent, when the engine begins to run above the proper speed. When the catch is thrown out, the valve is closed by a weight or a strong spring. To prevent jar when the motion of the valve is checked, a "dash-pot" is used, invented originally by F. E. Sickels. This is a vessel having a nicely-fitted piston, which is received by a "cushion" of water or air when the piston suddenly enters the cylinder at the end of the valve-movement. In the original water dash-pot of Sickels, the cylinder is vertical, and the plunger

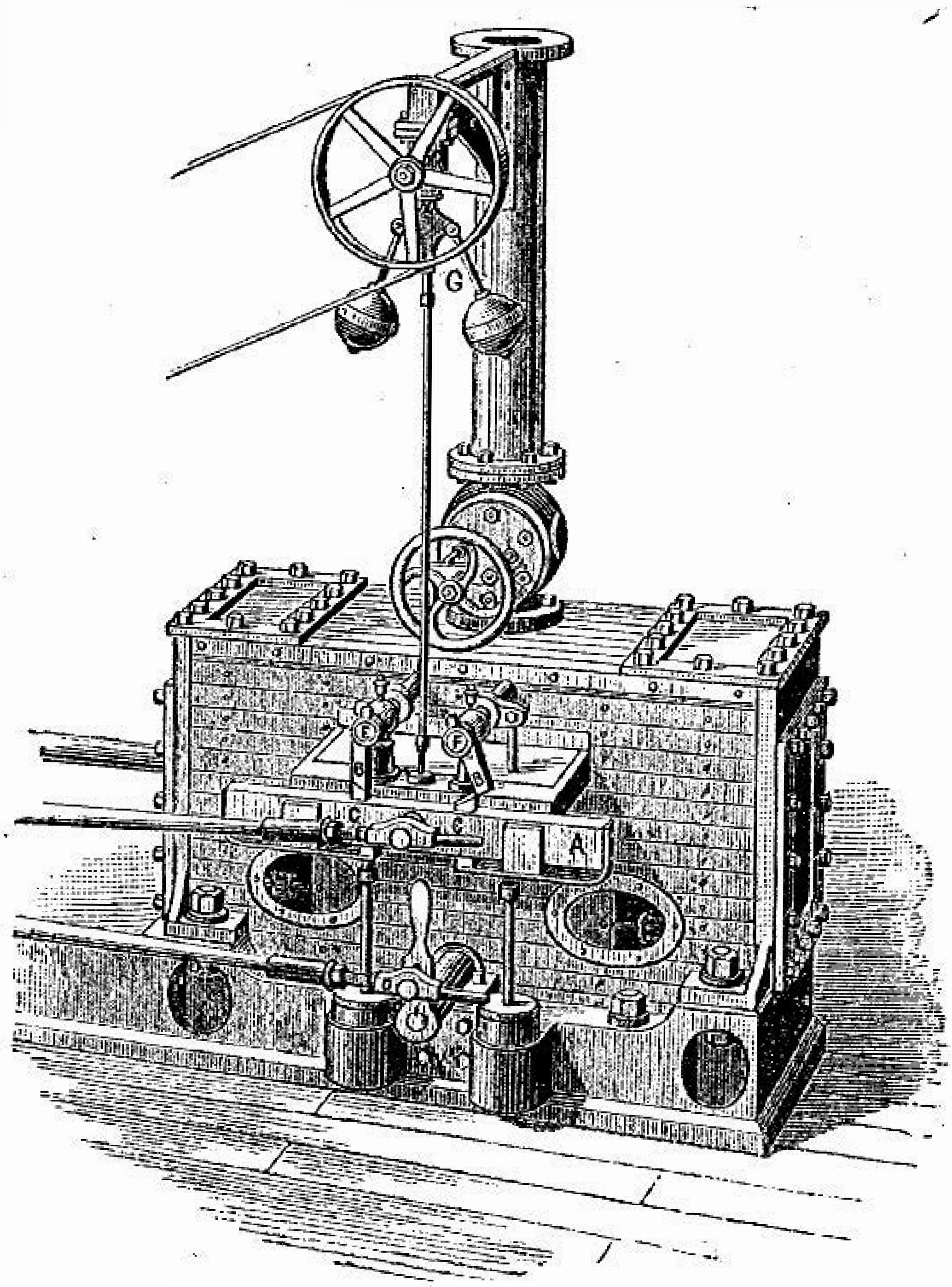


FIG. 99.—Greene Engine.

or piston descends upon a small body of water confined in the base of the dash-pot. Corliss's air dash-pot is now often set horizontally.

In the Greene steam-engine (Fig. 99), the valves are four in number, as in the Corliss. The cut-off gear consists of a bar, *A*, moved by the steam-eccentric in a direction parallel with the centre-line ofnthe cylinder and nearly coincident as to time with the piston. On this bar are tappets, *C C*, supported by springs and adjustable in height by the governor, *G*. These tappets engage the arms *B B*, on the ends of rock-shafts, *E E*, which move the steam-valves and remain in contact with them a longer or shorter time, and holding the valve open during a greater or less part of the piston-stroke, as the governor permits the tappets to rise with diminishing engine-speed, or forces them down as speed increases. The exhaust-valves are moved by annindependent eccentric rod, which is itself moved by an eccen-

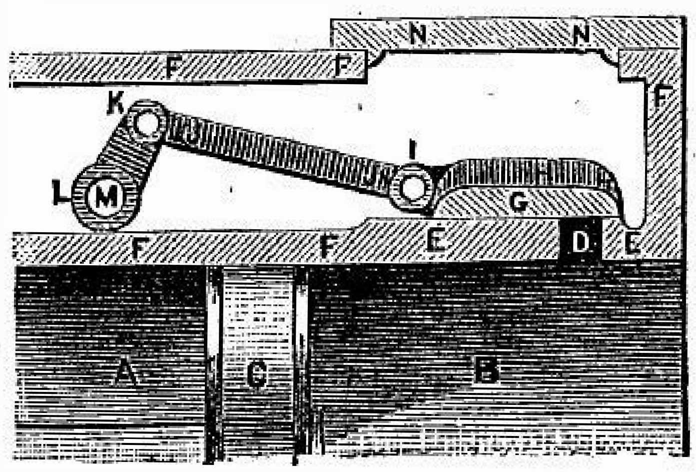


FIG. 100.—Thurston's Greene-Engine Valve-Gear.

tric set, as is usual with the Corliss and with other engines generally, at right angles with the crank. This engine, in consequence of the independence of the steam-eccentric, and of the contemporary movement of steam valve-motion and steam-piston, is capable of cutting off at any point from beginning to nearly the end of the stroke. The usual arrangement, by which steam and exhaust valves are moved by the same eccentric, only permits expansion with the range from the beginning to half-stroke. In the Corliss engine the latter construction is retained, with the object, in part, of securing a means of closing the valve by a "positive motion," should, by any accident, the closing not be effected by the weight or spring usually relied upon.

The steam-valve of the Greene engine, as designed by the author, is seen in Fig. 100, where the valve, *G H*, covering the port, *D*, in the steam-cylinder, *A B*, is moved by the rod, *J J*, connected to the rock-shaft, *M*, by the arm, *L K*. The line, *K I*, should, when carried out, intersect the valve-face at its middle point, under *G*.

The characteristics of the American stationary engine, therefore, are high steam-pressure without condensation, an expansion valve-gear with drop cut-off adjustable by the governor, high piston-speed, and lightness combined with strength of construction. The pressure most commonly adopted in the boilers which furnish steam to this type of engine is from 75 to 80 pounds per square inch; but a pressure of 100 pounds is not infrequently carried, and the latter pressure may be regarded as a "mean maximum," corresponding to a pressure of 60 pounds at about the commencement of the period here considered—1850.

Very much greater pressures have, however, been adopted by some makers, and immensely "higher steam" has been experimented with by several engineers. As early as 1823, Jacob Perkins[1] commenced experimenting with steam of very great tension. As has already been stated, the usual pressure at the time of Watt was but a few pounds—5 or 7—in excess of that of the atmosphere. Evans, Trevithick, and Stevens, had previously worked steam at pressures of from 50 to 75 pounds per square inch, and pressures on the Western rivers and elsewhere in the United States had already been raised to 100 or 150 pounds, and explosions were becoming alarmingly frequent.

Perkins's experimental apparatus consisted of a copper boiler, of a capacity of about one cubic foot, having sides 3 inches in thickness. It was closed at the bottom and top, and had five small pipes leading from the upper head.

[1] Perkins was a native of Newburyport, Mass. He was born July 9, 1766, and died in London, July 30, 1849. He went to England when fifty-two years of age, to introduce his inventions.

This was placed in a furnace kept at a high temperature by a forced combustion. Safety-valves loaded respectively to 425 and 550 pounds per square inch were placed on each of two of the steam-pipes.

Perkins used the steam generated under these great pressures in a little engine having a piston 2 inches in diameter and a stroke of 1 foot. It was rated at 10 horse-power.[1]

In the year 1827, Perkins had attained working pressures, in a single-acting, single-cylinder engine, of upward of 800 pounds per square inch. At pressures exceeding 200 pounds, he had much trouble in securing effective lubrication, as all oils charred and decomposed at the high temperatures then unavoidably encountered, and he finally succeeded in evading this seemingly insurmountable obstacle by using for rubbing parts a peculiar alloy which required no lubrication, and which became so beautifully polished, after some wear, that the friction was less than where lubricants were used. At these high pressures Perkins seems to have met with no other serious difficulty. He condensed the exhaust-steam and returned it to the boiler, but did not attempt to create a vacuum in his condenser, and therefore needed no air-pump. Steam was cut off at one-eighth stroke.

In the same year, Perkins made a compound engine on the Woolf plan, and adopted a pressure of 1,400 pounds, ex-

[1] It was when writing of this engine that Stuart wrote, in 1824: "Judging from the rapid strides the steam-engine has made *during the last forty years* to become a universal first-mover, and from the experience that has arisen from that extension, we feel convinced that every invention which diminishes its size without impairing its power brings it a step nearer to the assistance of the 'world's great laborers,' the husbandman and the peasant, for whom, as yet, it performs but little. At present, it is made occasionally to tread out the corn. What honors await not that man who may yet direct its mighty power to plough, to sow, to harrow, and to reap!" The progress of the steam-engine during those forty years does not to-day appear so astounding. The sentiment here expressed has lost none of its truth, nevertheless.

panding eight times. In still another engine, intended for a steam-vessel, Perkins adopted, or proposed to adopt, 2,000 pounds pressure, cutting off the admission at one-sixteenth, in single-acting engines of 6 inches diameter of cylinder and 20 inches stroke of piston. The steam did not retain boiler-pressure at the cylinder, and this engine was only rated at 30 horse-power.[1]

Stuart follows a description of Perkins's work in the improvement of the steam-engine and the introduction of steam-artillery by the remark :

". . . . No other mechanic of the day has done more to illustrate an obscure branch of philosophy by a series of difficult, dangerous, and expensive experiments ; no one's labors have been more deservingnof cheering encouragement, and no one has received less. Even in their present state, his experiments are opening new fields for philosophical research, and his mechanism bids fair to introduce a new style into the proportions, construction, and form, of steam-machinery."

Perkins's experience was no exception to the general rule, which denies to nearly all inventors a fair return for the benefits which they confer upon mankind.

Another engineer, a few years later, was also successful in controlling and working steam under much higher pressures than are even now in use. This was Dr. Ernst Alban, a distinguished German engine-builder, of Plau, Mecklenburg, and an admirer of Oliver Evans, in whose path he, a generation later, advanced far beyond that great pioneer. Writing in 1843, he describes a system of engine and boiler construction, with which he used steam under pressures about equal to those experimentally worked by Jacob Perkins, Evans'snAmerican successor. Alban's treatise was translated and printed in Great Britain,[2] four years later.

[1] Galloway and Hebert, on the Steam-Engine. London, 1836.

[2] "The High-Pressure Steam-Engine," etc. By Dr. Ernst Alban. Translated by William Pole, F. R. A. S. London, 1847.

Alban, on one occasion, used steam of 1,000 pounds pressure. His boilers were similar in general form to the boiler patented by Stevens in 1805, but the tubes were horizontal instead of vertical. He evaporated from 8 to 10 pounds of water into steam of 600 to 800 pounds pressure with each pound of coal. He states that the difficulty met by Perkins—the decomposition of lubricants in the steam-cylinder—did not present itself in his experiments, even when working steam at a pressure of 600 pounds on the square inch, and he found that less lubrication was needed at such high pressures than in ordinary practice. Alban expanded his steam about as much as Evans, in his usual practice, carrying a pressure of 150 pounds, and cutting off at one-third; he adopted greatly increased piston-speed, attaining 300 feet per minute, at a time when common practice had only reached 200 feet. He usually built an oscillating engine, and rarely attached a condenser. The valve was the locomotive-slide.[1] The stroke was made short to secure strength, compactness, cheapness, and high speed of rotation; but Alban does not seem to have understood the principles controlling the form and proportions of the expansive engine, or the necessity of adopting considerable expansion in order to secure economy in working steam of great tension, and therefore was, apparently, not aware of the advantages of a long stroke in reducing losses by "dead-space," in reducing risk of annoyance by hot journals, or in enabling high piston-speeds to be adopted. He seems never to have attained a sufficiently high speed of piston to become aware that the oscillating cylinder cannot be used at speeds perfectly practicable with the fixed cylinder.

Alban states that one of his smallest engines, having a cylinder 4½ inches in diameter and 1 foot stroke of piston, with a piston-speed of but 140 to 160 feet per minute, developed 4 horse-power, with a consumption of 5.3 pounds

[1] Invented by Joseph Maudsley, of London, 1827.

of coal per hour. This is a good result for so small an amount of work, and for an engine working at so low a speed of piston. An engine of 30 horse-power, also working very slowly, required but 4.1 pounds of coal per hour per horse-power.

The work of Perkins and of Alban, like that of their predecessors, Evans, Stevens, and Trevithick, was, however, the work of engineers who were far ahead of their time. The general practice, up to the time which marked the beginning of the modern "period of refinement," had been but gradually approximating that just described. Higher pressures were slowly approached ; higher piston-speeds came slowly into use ; greater expansion was gradually adopted; the causes of losses of heat were finally discovered, and steam-jacketing and external non-conducting coverings were more and more generally applied as builders became more familiar with their work. The "compound engine" was now and then adopted ; and each experiment, made with higher steam and greater expansion, was more nearly successful than the last.

Finally, all these methods of securing economy became recognized, and the reasons for their adoption became known. It then remained, as the final step in this progression, to combine all these requisites of economical working in a double-cylinder engine, steam-jacketed, well protected by non-conducting coverings, working steam of high pressure, and with considerable expansion at high piston-speed. This is now done by the best builders.

One of the best examples of this type of engine is that constructed by the sons of Jacob Perkins, who continued the work of their father after his death. Their engines are single-acting, and the small or high-pressure cylinder is placed on the top of the larger or low-pressure cylinder. The valves are worked by rotating stems, and the loss of heat and burning of packing incident to the use of the common method are thus avoided. The stuffing-boxes are placed at the end of long sleeves, closely surrounding the vertical valve-stems also, and the water of condensation which collects in these sleeves is an additional and thorough protection against excessively high temperature at the packing. The piston-rings are made of the alloy which has been found to require no lubrication.

Steam is usually worked at from 250 to 450 pounds, and is generated in boilers composed of small tubes three inches in diameter and three-eighths of an inch thick, which are tested under a pressure of 2,500 pounds per square inch. The safety-valve is usually loaded to 400 pounds. The boiler is fed with distilled water, obtained principally by condensation of the exhaust-steam, any deficiency being made up by the addition of water from a distilling apparatus. Under these conditions, but $1\frac{1}{4}$ pound of coal is consumed per hour and per horse-power.

THE PUMPING-ENGINE in use at the present time has passed through a series of changes not differing much from that which has been traced with the stationary mill-engine. The Cornish engine is still used to some extent for supplying water to towns, and is retained at deep mines. The modern Cornish engine differs very little from that of the time of Watt, except in the proportions of parts and the form of its details. Steam-pressures are carried which were never reached during the preceding period, and, by careful adjustment of well-set and well-proportioned valves and gearing, the engine has been made to work rather more rapidly, and to do considerably more work. It still remains, however, a large, costly, and awkward contrivance, requiring expensive foundations, and demanding exceptional care, skill, and experience in management. It is gradually going out of use. This engine, as now constructed by good builders, is shown in section in Fig. 101.

A comparison with the Watt engine of a century earlier will at once enable any one to appreciate the extent to which changes may be made in perfecting a machine, even after it has become complete, so far as supplying it with all essential parts can complete it.

In the figure, *A* is the cylinder, taking steam from the boiler through the steam-passage, *M*. The steam is first admitted above the piston, *B*, driving it rapidly downward

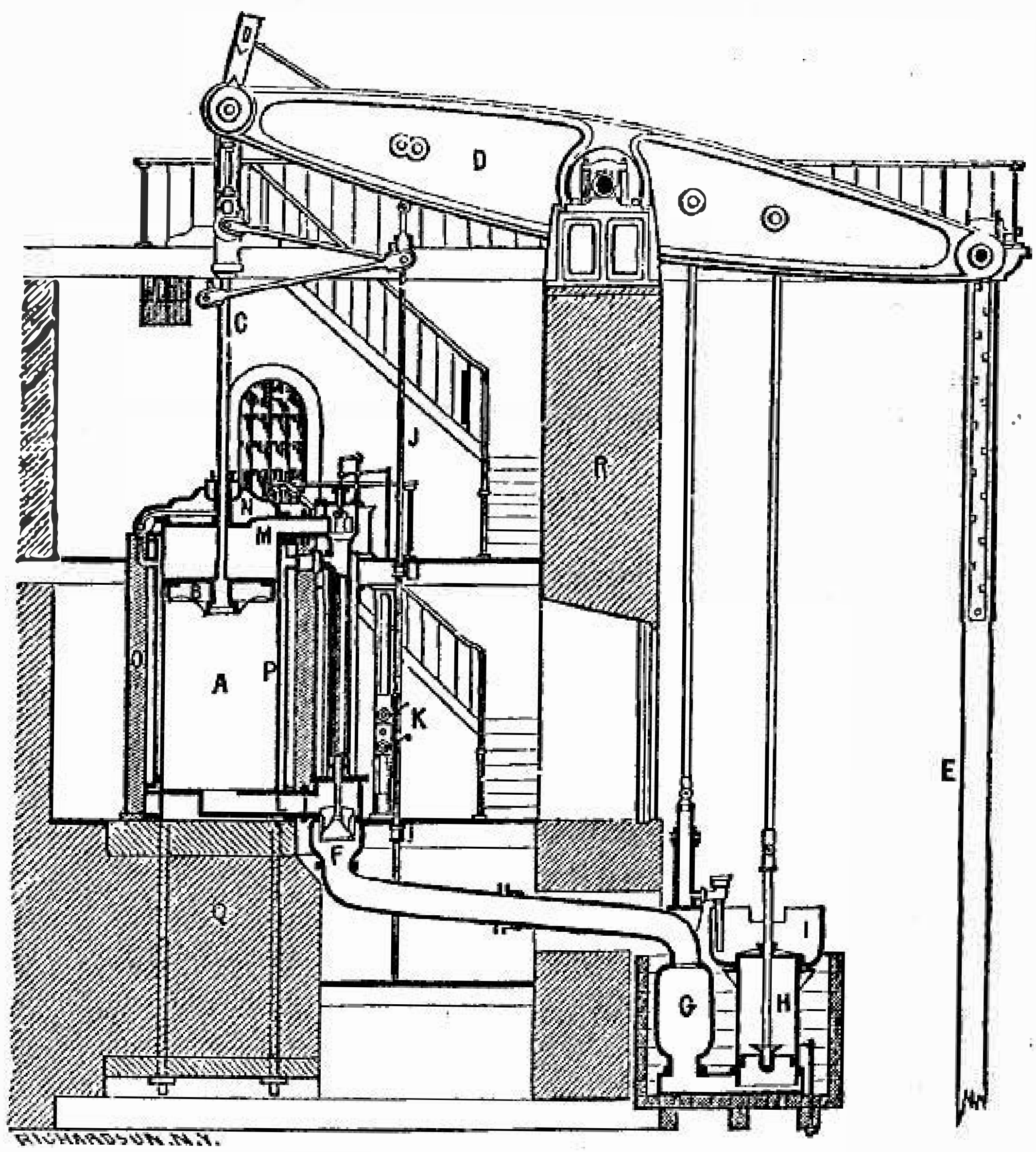


FIG. 101.—Cornish Pumping-Engine, 1880.

and raising the pump-rod, *E*. At an early period in the stroke the admission of steam is checked by the sudden closing of the induction-valve at *M*, and the stroke is completed under the action of expanding steam assisted by the inertia of the heavy parts already in motion. The necessary weighteand inertia is afforded,ein many cases, where the engine is applied to the pumping of deep mines, by the immensely long and heavy pump-rods. Where this weight is too great, it is counterbalanced, and where too small, weights are added. When the stroke is completed, the "equilibrium valver" is opened, and the steam passes from above to the space below the piston, and an equilibrium of pressure being thus produced, the pump-rods descend, forcing the water from the pumps and raising the steam-piston. The absence of the crank, or other device which might determine absolutely the length of stroke, compels a very careful adjustment of steam-admission to the amountr of load. Should the stroke be allowed to exceed the proper length, and should danger thus arise of the piston striking the cylinder-head, *N*, the movement is checked by buffer-beams. The valve-motion is actuated by a plug-rod, *J K*, as in Watt's engine. The regulation is effected by a "cataract," a kind of hydraulic governor, consisting of a plunger-pump, with a reservoir attached. The plunger is raised by the engine, and then automatically detached. It falls with greater or less rapidity, its velocity being determined by the size of the eduction-orifice, which is adjustable by hand. When the plunger reaches the bottom of the pump-barrel, it disengages a catch, a weight is allowed to act upon the steam-valve, opening it, and the engine is caused to make a stroke. When the outlet of the cataract is nearly closed, the engine stands still a considerable time while the plunger is descending, and the strokes succeed each other at long intervals. When the opening is greater, the cataract acts more rapidly, and the engine works faster. This has been regarded until recently as the most economical of pumping-engines, and it is still generally used in freeing mines of water, and in situations where existing heavy pump-rods may be utilized in counterbalancing the steam-pressure, and, by their inertia, in continuing the motion after the steam, by its expansion, has become greatly reduced in pressure.

In this engine a gracefully-shaped and strong beam, *D*, has taken the place of the ruder beam of the earlier period, and is carried on a well-built wall of masonry, *R*. *F* is the exhaust-valve, by which the beam passes to the condenser, *G*, beside which is the air-pump, *H*, and the hot-well, *I*. The cylinder is steam-jacketed, *P*, and protected against losses of heat by radiation by a brick wall, *O*, the whole resting on a heavy foundation, *Q*.

The Bull Cornish engine is also still not infrequently seen in use. The Cornish engine of Great Britain averages a duty of about 45,000,000 pounds raised one foot high per 100 pounds of coal. More than double this economy has sometimes been attained.

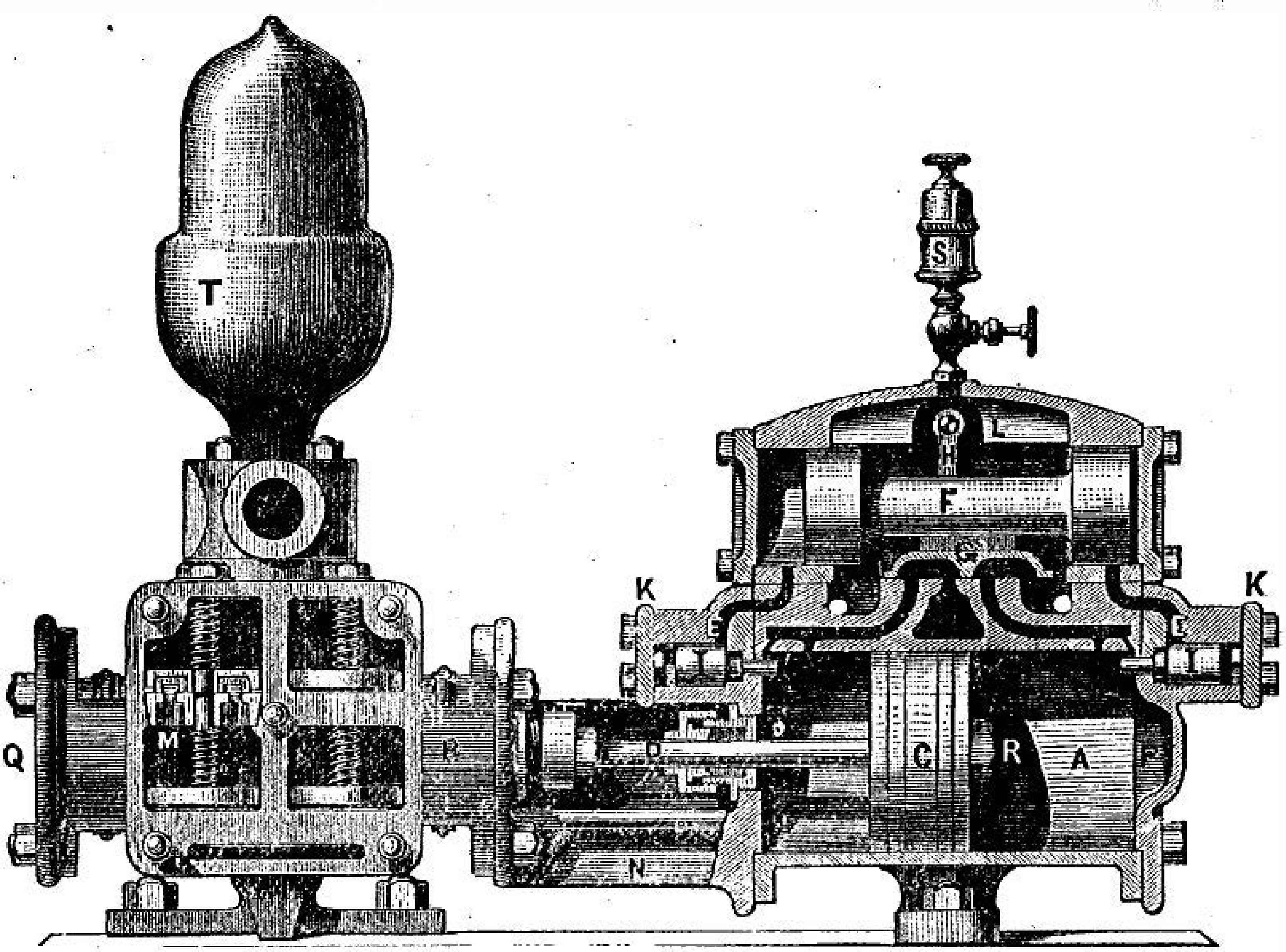


FIG. 102.—Steam-Pump.

A vastly simpler form of pumping-engine without fly-wheel is the now common "direct-acting steam-pump." This engine is generally made use of in feeding steam-boilers, as a forcing and fire pump, and wherever the amount of water to be moved is not large, and where the pressure is comparatively great. The steam-cylinder, *A R*, and feed-pump, *B Q* (Fig. 102), are in line, and the two pistons have usually one rod, *D*, in common. The two cylinders are connected by a strong frame, *N*, and two standards fitted with lugs carry the whole, and serve as a means of bolting the pump to the floor or to its foundation.

The method of working the steam-valve of the modern steam-pump is ingenious and peculiar. As shown, the pistons are moving toward the left; when they reach the end of their stroke, the face of the piston strikes a pin or other contrivance, and thus moves a small auxiliary valve, *I*, which opens a port, *E*, and causes steam to be admitted behind a piston, or permits steam to be exhausted, as in the figure, from before the auxiliary piston, *F*, and the pressure within the main steam-chest then forces that piston over, moving themain steam-valve, *G*, to which it is attached, admitting steam to the left-hand side of the main piston, and exhausting on the right-hand side, *A*. Thus the motion of the engine operates its own valves in such a manner that it is never liable to stop working at the end of the stroke, notwithstanding the absence of the crank and fly-wheel, or of independent mechanism, like the cataract of the Cornish engine. There is a very considerable variety of pumps of this class, all differing in detail, but all presenting the distinguishing feature of auxiliary valve and piston, and a connection by which it and the main engine each works the valve of the other combination.

In some cases these pumps are made of considerable size, and are applied to the elevation of water in situations to which the Cornish engine was formerly considered exclusively applicable. The accompanying figure illustrates such a pumping-engine, as built for supplying cities with water. This is a "compound" direct-acting pumping-engine. The cylinders, *A B*, are placed in line, working one pump, *F*, and operating their own air-pumps, *D D*, by a bell-crank lever, *L H*, connected to the pump-buckets by links, *I K*. Steam exhausted from the small cylinder, *A*, is further expanded in the large cylinder, *B*, and thence goes to the

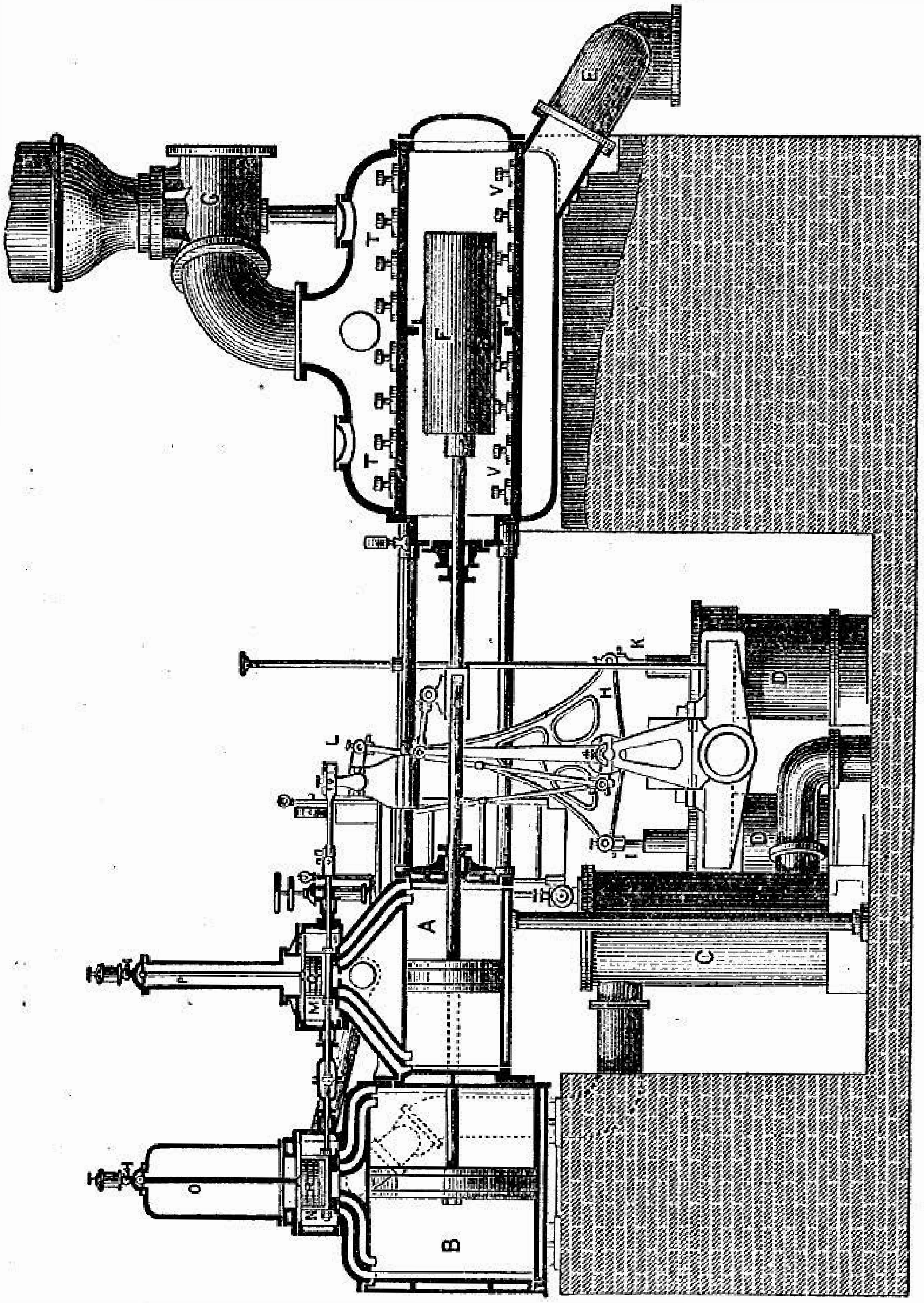


FIG. 108.—The Worthington Pumping-Engine, 1876. Section.

condenser, *C*. The valves, *N M*, are moved by the valve-gear, *L*, which is actuated by the piston-rod of a similar pair of cylinders placed by the side of the first. These valves are balanced, and the balance-plates, *R Q*, are suspended from the rods, *O P*, which allow them to move with the valves. By connecting the valves of each engine with

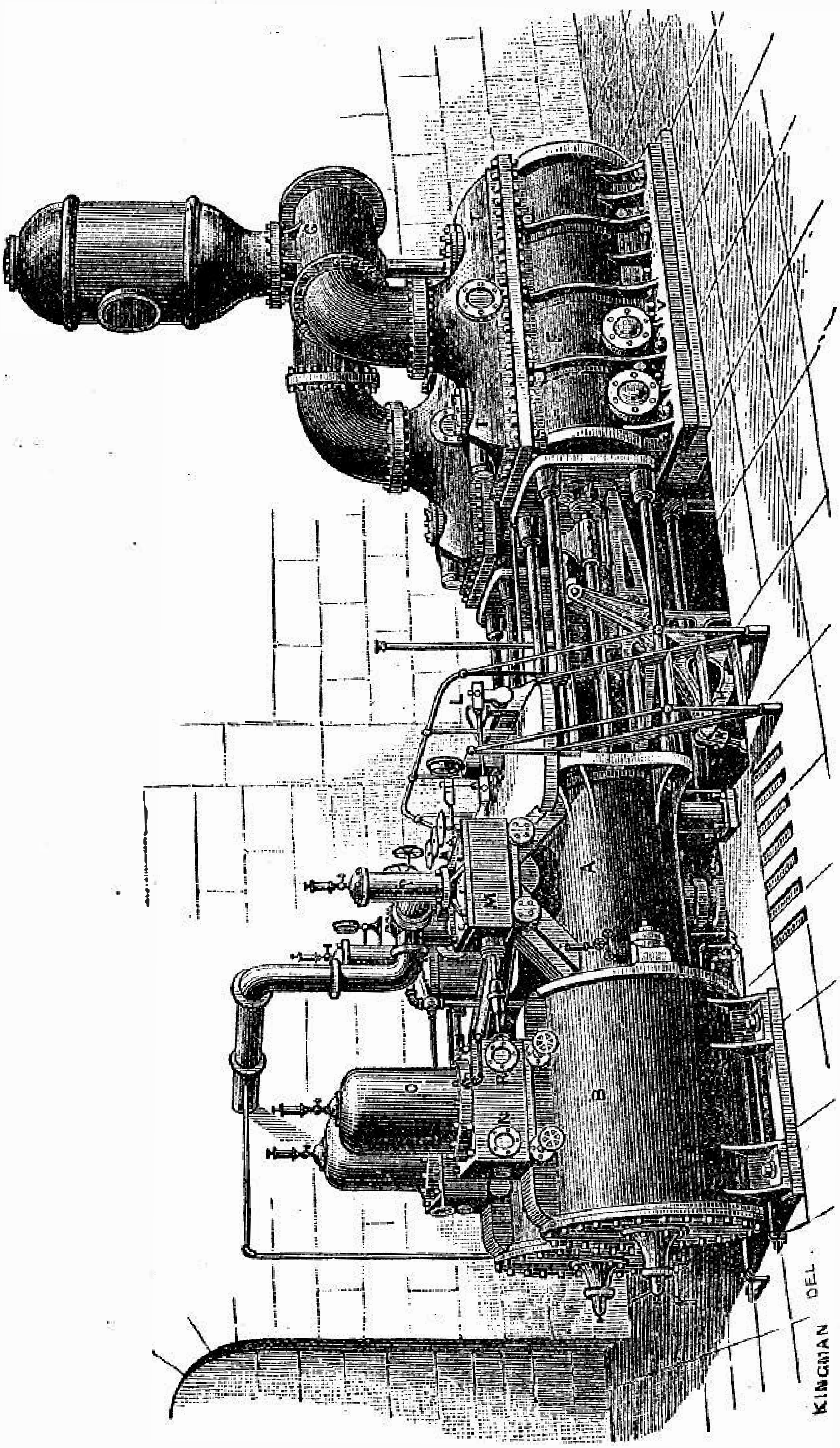


FIG. 104.—The Worthington Pumping-Engine.

the piston-rod of the other, itnis seen that the two engines must work alternately, the one making a stroke while the other is still, and then itself stopping a moment while the latter makes its stroke.n

Water enters the pump through the induction-pipe, *E*, passes into the pump-barrel through the valves, *V V*, and issues through the eduction-valves, *T T*, and goes on to the "mains" by the pipe, *G*, above which is seen an air-chamber, which assists to preserve a uniform pressure on that side the pump. This engine works very smoothly and quietly, is cheap and durable, and has done excellent duty.

Beam pumping-engines are now almost invariably built with crank and fly-wheel, and very frequently are compound engines. The accompanying illustration represents an engine of the latter form.

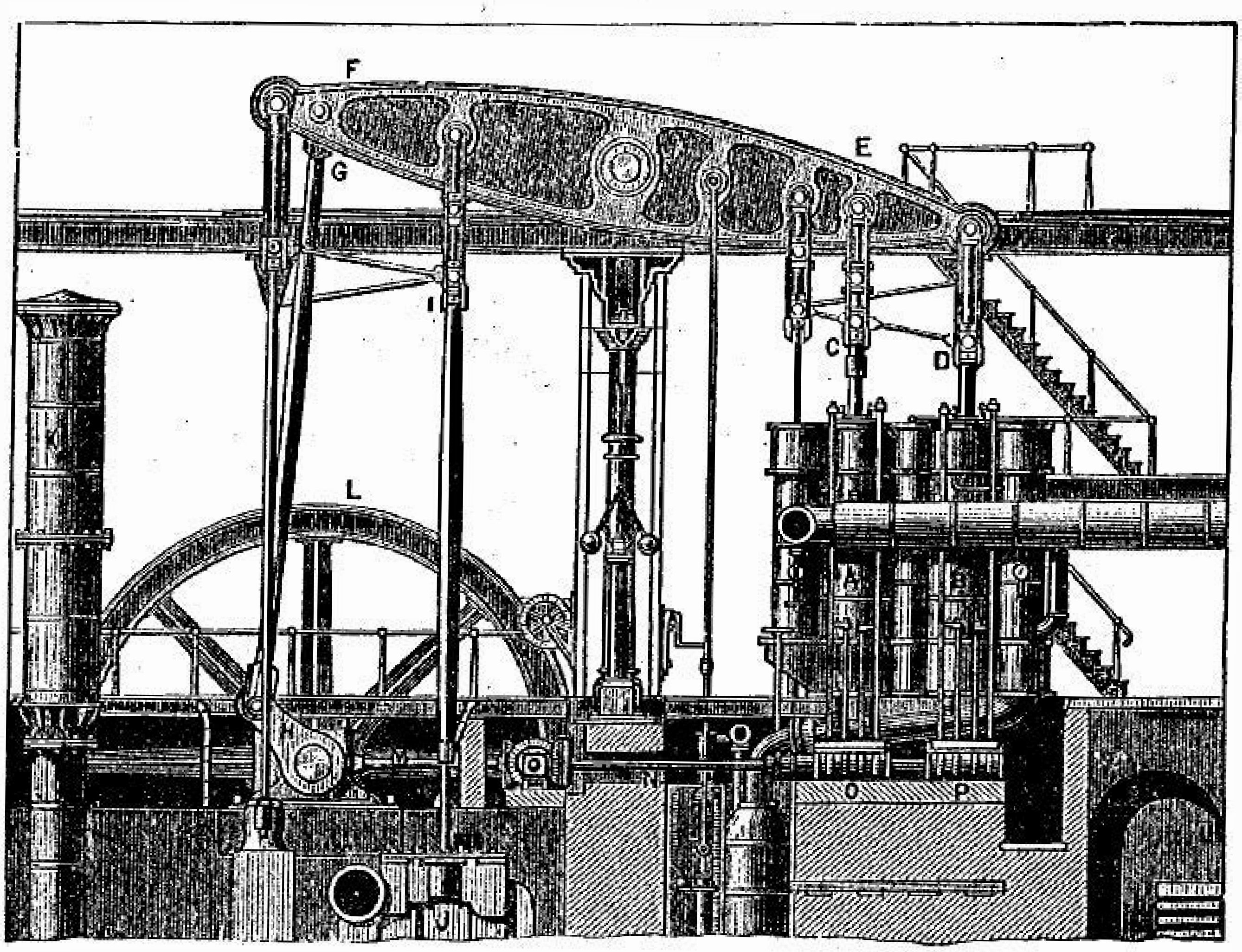


FIG. 105.—Double-Cylinder Pumping-Engine, 1878.

A and *B* are the two steam-cylinders, connected by links and parallel motion, *C D*, to the great cast-iron beam, *E F*. At the opposite end of the beam, the connecting-rod; *G*, turns a crank, *H*, and fly-wheel, *L M*, which regulates the motion of the engine and controls the length of stroke, averting all danger of accident occurring in conse-

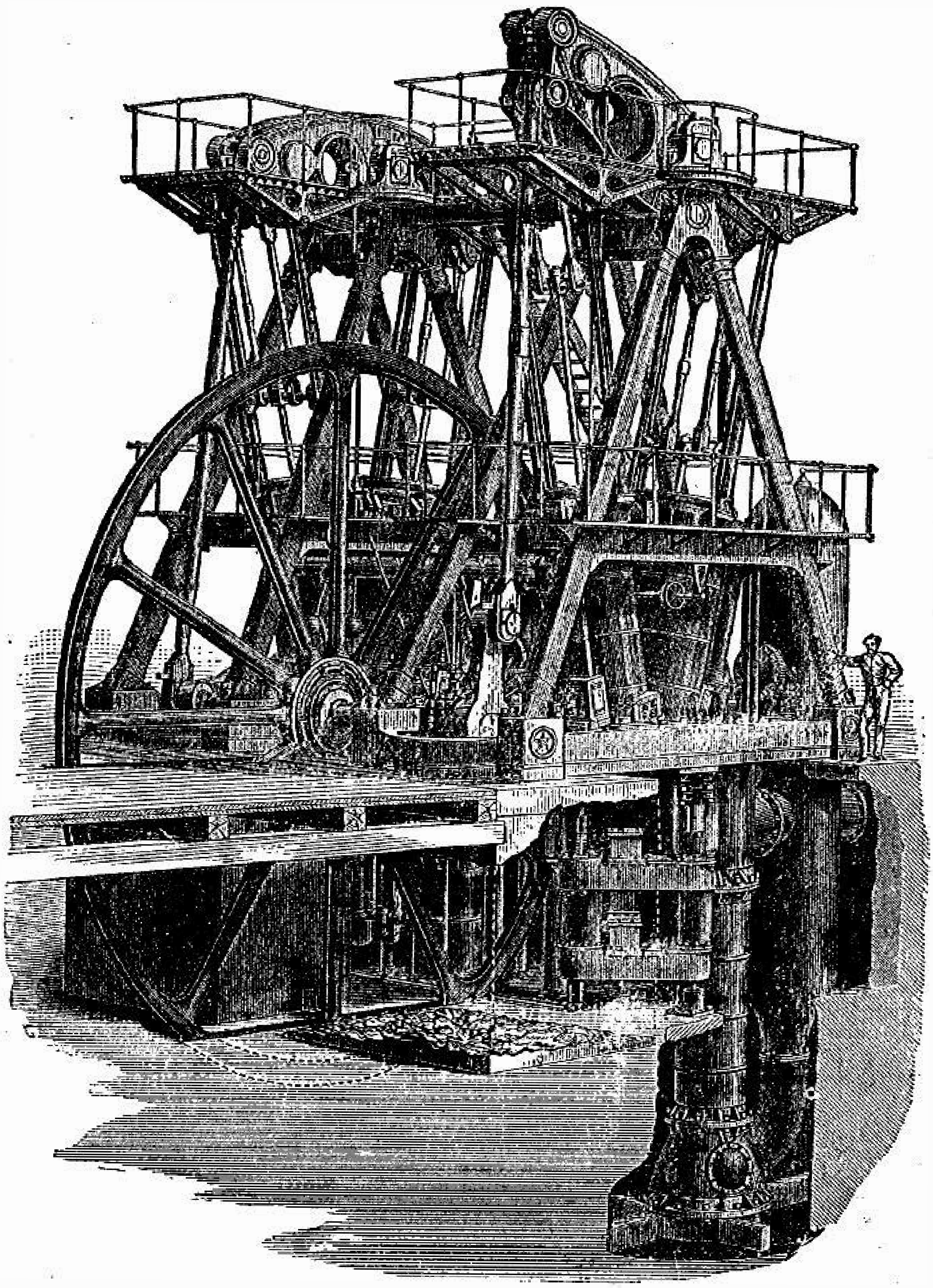


FIG. 106.—The Lawrence Water-Works Engine.

quence of the piston striking either cylinder-head. The beam is carried on handsomely-shaped iron columns, which, with cylinders, pump, and fly-wheel, are supported by a substantial stone foundation. The pump-rod, *I*, works a double-acting pump, *J*, and the resistance to the issuing water is rendered uniform by an air-chamber, *K*, within which the water rises and falls when pressures tend to vary greatly. A revolving shaft, *N*, driven from the fly-wheel shaft, carries cams, *O P*, which move the lifting-rods seen directly over them and the valves which they actuate. Between the steam-cylinders and the columns which carry the beams is a well, in which are placed the condenser and air-

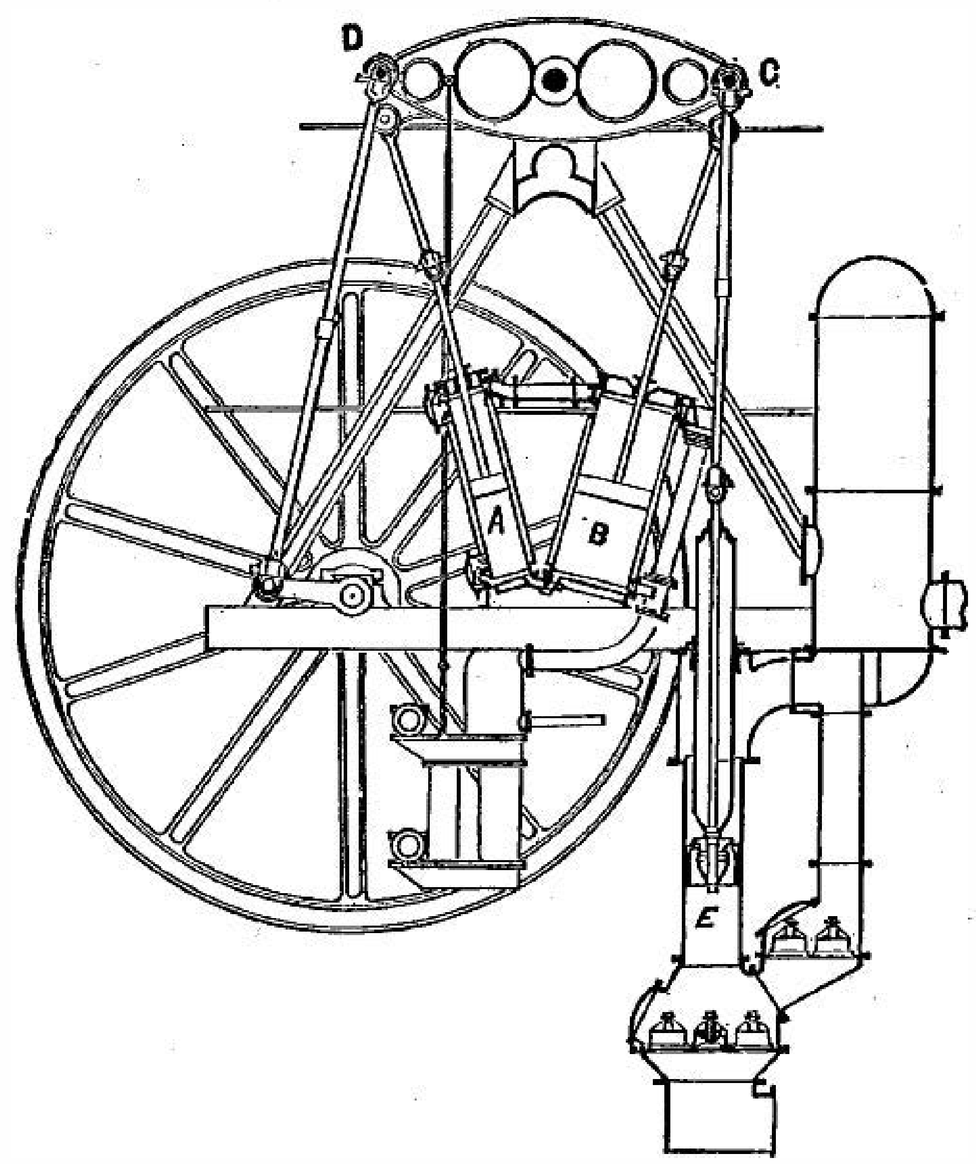


FIG. 107.—The Leavitt Pumping-Engine.

pump. Steam is carried at 60 or 80 pounds pressure, and expanded from 6 to 10 times.

A later form of double-cylinder beam pumping-engine is that invented and designed by E. D. Leavitt, Jr., for the Lawrence Water-Works, and shown in Figs. 106 and 107. The two cylinders are placed one on each side the centre of the beam, and are so inclined that they may be coupled to opposite ends of it, while their lower ends are placed close together. At their upper ends a valve is placed at each end of the connecting steam-pipe. At their lower ends a single valve serves as exhaust-valve to the high-pressure and as steam-valve to the low-pressure cylinder. The pistons move in opposite directions, and steam is exhausted from the high-pressure cylinder directly into the nearer end of the low-pressure cylinder. The pump, of the "Thames-Ditton" or "bucket-and-plunger" variety, takes a full supply of water on the down-stroke, and discharges half when rising and half when descending again. The duty of this engine is reported by a board of engineers as 103,923,215 foot-pounds for every 100 pounds of coal burned. The duty of a moderately good engine is usually considered to be from 60 to 70 millions. This engine has steam-cylinders of 17½ and 36 inches diameter respectively, with a stroke of 7 feet. The pump had a capacity of about 195 gallons, and delivered 96 per cent. Steam was carried at a pressure of 75 pounds above the atmosphere, and was expanded about 10 times. Plain horizontal tubular boilers were used, evaporating 8.58 pounds of water from 98° Fahr. per pound of coal.

STEAM-BOILERS.—The steam supplied to the forms of stationary engine which have been described is generated in steam-boilers of exceedingly varied forms. The type used is determined by the extent to which their cost is increased in the endeavor to economize fuel by the pressure of steam carried, by the greater or less necessity of providing against risk of explosion, by the character of the feed-water to be used, by the facilities which may exist for keeping in good repair, and even by the character of the men in whose hands the apparatus is likely to be placed.

As has been seen, the changes which have marked the growth and development of the steam-engine have been accompanied by equally marked changes in the forms of the steam-boiler. At first, the same vessel served the distinct purposes of steam-generator and steam-engine. Later, it became separated from the engine, and was then specially fitted to perform its own peculiar functions ; and its form went through a series of modifications under the action of the causes already stated.

When steam began to be usefully applied, and considerable pressures became necessary, the forms given to boilers were approximately spherical, ellipsoidal, or cylindrical. Thus the boilers of De Caus (1615) and of the Marquis of Worcester (1663) were spherical and cylindrical; those of Savery (1698) were ellipsoidal and cylindrical. After the invention of the steam-engine of Newcomen, the pressures adopted were again very low, and steam-boilers were given irregular forms until, at the beginning of the present century, they were again of necessity given stronger shapes. The material was at first frequently copper; it is now usually wrought-iron, and sometimes steel.

The present forms of steam-boilers may be classified as plain, flue, and tubular boilers. The plain cylindrical or common cylinder boiler is the only representative of the first class in common use. It is perfectly cylindrical, with heads either flat or hemispherical. There is usually attached to the boiler a "steam-drum" (a small cylindrical vessel), from which the steam is taken by the steam-pipe. This enlargement of the steam-space permits the mist, held in suspension by the steam when it first rises from the surface of the water, to separate more or less completely before the steam is taken from the boiler.

Flue-boilers are frequently cylindrical, and contain one or more cylindrical flues, which pass through from end to end, beneath the water-line, conducting the furnace-gases, and affording a greater area of heating-surface than can be obtained in the plain boiler. They are usually from 30 to 48 inches in diameter, and one foot or less in length for each inch of diameter. Some are, however, made 100 feet and more in length. The boiler is made of iron $\frac{1}{4}$ to $\frac{3}{8}$ of an inch in thickness, with hemispherical or carefully stayed flat heads, and without flues. The whole is placed in a brickwork setting. These boilers are used where fuel is inexpensive, where the cost of repairing would be great, or where the feed-water is impure. A cylindrical boiler, having one flue traversing it longitudinally, is called a Cornish boiler, as it is generally supposed to have been first used in Cornwall. It was probably first invented by Oliver Evans in the United States, previous to 1786, at which time he had it in use. The flue has usually a diameter 0.5 or 0.6 the diameter of the boiler. A boiler containing two longitudinal flues is called the Lancashire boiler. This form was also introduced by Oliver Evans. The flues have one-third the diameter of the boiler. Several flues of smaller diameter are often used, and when a still greater proportional area of heating-surface is required, tubes of from $1\frac{1}{4}$ inch to 4 or 5 inches in diameter are substituted for flues. The flues are usually constructed by riveting sheets together, as in making the shell or outer portion. They are sometimes welded by British manufacturers, but rarely if ever in the United States. Tubes are always "lap-welded" in the process of rolling them. Small tubes were first used in the United States, about 1785. In portable, locomotive, and marine steam-boilers, the fire must be built within the boiler itself, instead of (as in the above described stationary boilers) in a furnace of brickwork exterior to the boiler. The flame and gases from the furnace or fire-box in these kinds of boiler are never led through brick passages *en route* to the chimney, as often in the preceding case, but are invariably conducted through flues or tubes, or both, to the smoke-stack. These boilers are also sometimes used as stationary boilers. Fig. 108 represents such a steam-boiler in section, as it is usually exhibited in working drawings. Provision is made to secure a good circulation of water in these boilers by means of the "baffle-plates," seen in the sketch, which compel the water to flow as indicated by the arrows. The tubes are frequently made of brass or of copper, to secure rapid transmission of heat to the water, and thus to permit the use of a smaller area of heating-surface

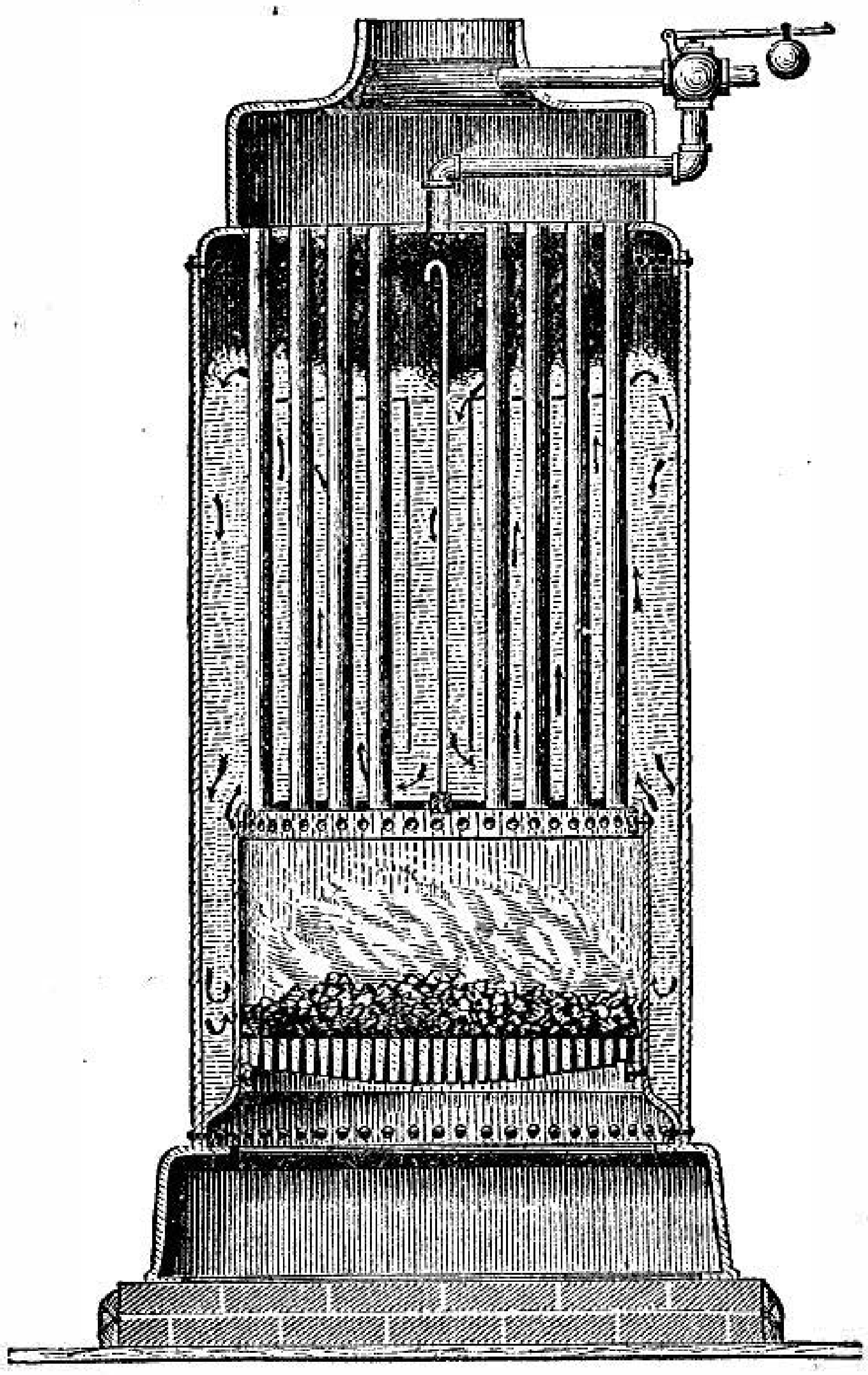


FIG. 108.—Babcock & Wilcox's Vertical Boiler.

and a smaller boiler. The steam-space is made as large as possible, to secure immunity from "priming" or the "entrainment" of water with the steam. This type of steam-boiler, invented by Nathan Read, of Salem, Mass., in 1791, and patented in April of that year, was the earliest of the tubular boilers. In the locomotive boiler (Fig. 109), as in the preceding, the characteristics are a fire-box at one end of the shell and a set of tubes through which the gases pass directly to the smoke-stack. Strength, compactness, great steaming capacity, fair economy, moderate cost, and convenience of combination with the running parts, are secured by the adoption of this form. It is frequently used also for portable and stationary engines. It was invented in France by M. Séguin, and in England by Booth, and used by George Stephenson at about the same time—1828 or 1829.

Since the efficiency of a steam-boiler depends upon the extent of effective heating-surface per unit of weight of fuel burned in any given time—or, ordinarily, upon the ratio of the areas of heating and grate surface—peculiar

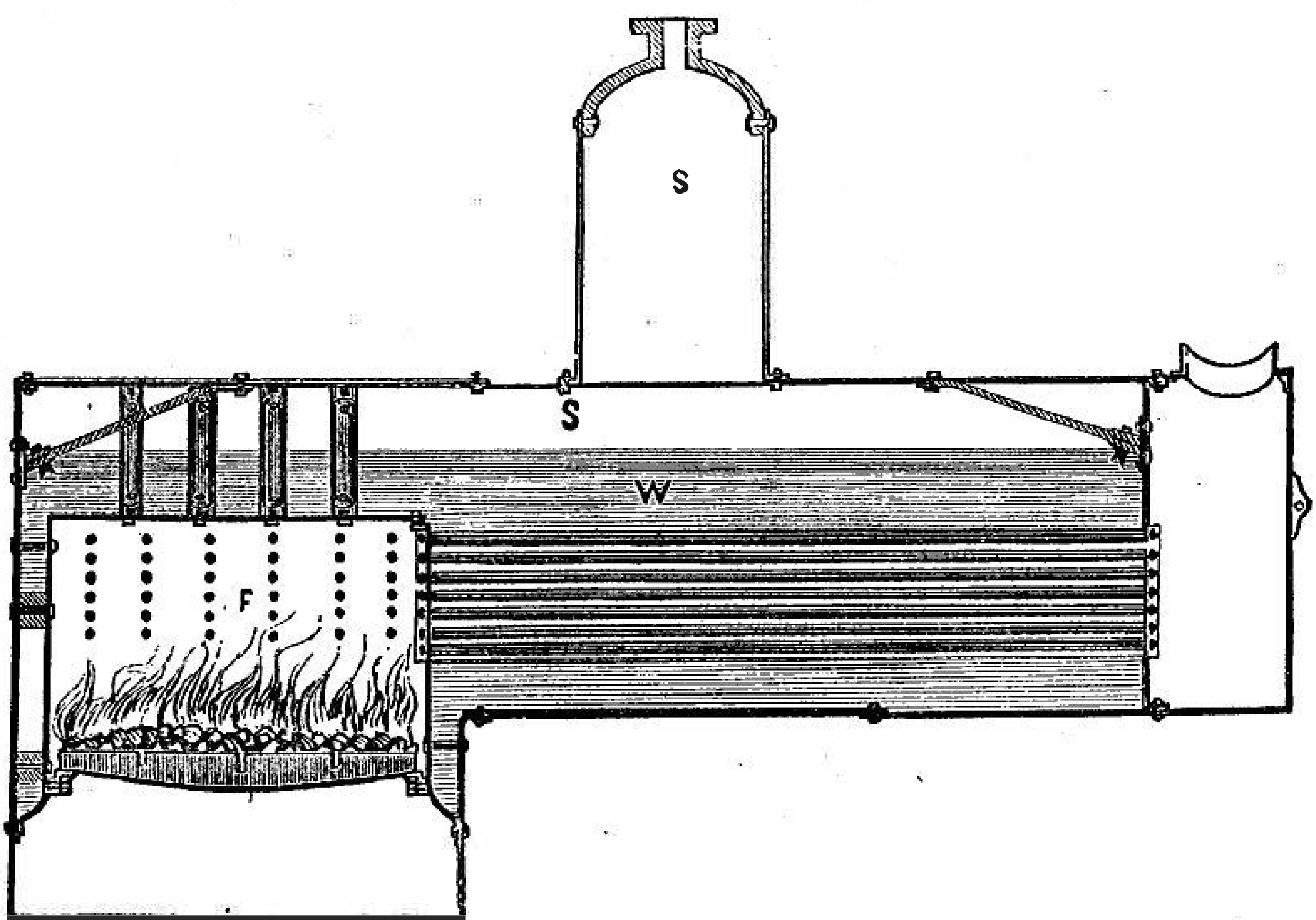


Fig. 109.—Stationary "Locomotive" Boiler.

expedients are sometimes adopted, having for their object the increase of heating-surface, without change of form of boiler and without proportionate increase of cost.

One of these methods is that of the use of Galloway conical tubes (Fig. 110). These are very largely used in

Great Britain, but are seldom if ever seen in the United States. The Cornish boiler, to which they are usually applied, consists of a large cylindrical shell, 6 feet or more in diameter, containing one tube of aboute one-half as great dimensions, or sometimes two of one-third the diameter of the shell each. Such boilers have a very small ratio of heating to grate surface, and their large tubes are peculiarly liable to collapse. To remove these objections, the Messrs. Galloway introduced stay-tubes into the flues, which tubes are conical in form, and are set in either a vertical or an inclined position, the larger end uppermost. The area of heating-surface is thus greatly increased, and, at the same time, the liability to collapse is reduced. The same results are obtained by another device of Galloway, which is sometimes combined with that just described in the same boiler. Several sheets in the flue have "pocketsė" worked into them, which pockets project into the flue-passage.

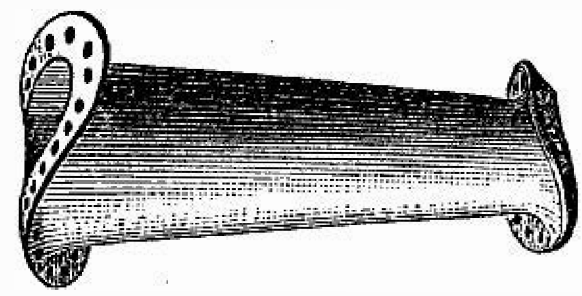


FIG. 110.

Another device is thateof an American engineer, Miller, who surrounds the furnace of cylindrical and other boilers with water-tubes.e The "fuel-economizersė" of Greene and others consist of similar collections of tubes set in the flues, between the boiler and the chimney.

"*Sectional*" boilers are gradually coming into use with high pressures, on account of their greater safety against disastrous explosions. The earliest practicable example of a boiler of this class was probably that of Colonel John Stevens, of Hoboken, N. J. Dr. Alban, who, forty years later, attempted to bring this type into general use, and constructed a number of such boilers, did not succeed. Their introduction, like that of all radical changes in engineering, has been but slow, and it has been only recently that their manufacture has become an important branch of industry.

A committee of the American Institute, of which the author was chairman, in 1871, examined several boilers of this and the ordinary type, and tested them very carefully. They reported that they felt "confident that the introduction of this class of steam-boilers will do much toward the removal of the cause of that universal feeling of distrust which renders the presence of a steam-boiler so objectionable in every locality. The difficulties in thoroughly inspecting these boilers, in regulating their action, and other faults of the class, are gradually being overcome, and the committee look forward with confidence to the time when their use will become general, to the exclusion of older and more dangerous forms of steam-boilers."

The economical performance of these boilers with a similar ratio of heating to grate surface is equal to that of other kinds. In fact, they are usually given a somewhat higher ratio, and their economy of fuel frequently exceeds that of the other types. Their principal defect is their small capacity for steam and water, which makes it extremely difficult to obtain steady steam-pressure. Where they are employed, the feed and draught should be, if possible, controlled by automatic attachments, and the feed-water heated to the highest attainable temperature. Their satisfactory working depends, more than in other cases, on the ability of the fireman, and can only be secured by the exercise of both care and skill.

Many forms of these boilers have been devised. Walter Hancock constructednboilers for his steam-carriage of flat plates connected by stay-bolts, several such sections composing the boiler ; and about the same time (1828) Sir Goldworthy Gurney constructed for a similar purpose boilers consisting of a steam and a water reservoir, placed one above the other, and connected by triangularly-bent water-tubes exposed to the heat of the furnace-gases. Jacob Perkins made many experiments looking to the employment of very high steam-pressures, and in 1831 patented a boiler of this class, in which the heating-surfaces nearest the fire were composed of iron tubes, which tubes also served as grate-bars. The steam and water space was principally comprised within a comparatively large chamber, of which the walls were secured by closely distributed stay-bolts. For extremely high pressures, boilers composed only of tubes were used. Dr. Ernst Alban described the boiler already referred to, and its construction and operation, and stated that he had experimented with pressures as high as 1,000 pounds to the square inch.

The Harrison steam-boiler, which has been many years in use in the United States, consists of several sections, each of which is made up of hollow globes of cast-iron, communicating with each other by necks cast upon the spheres,

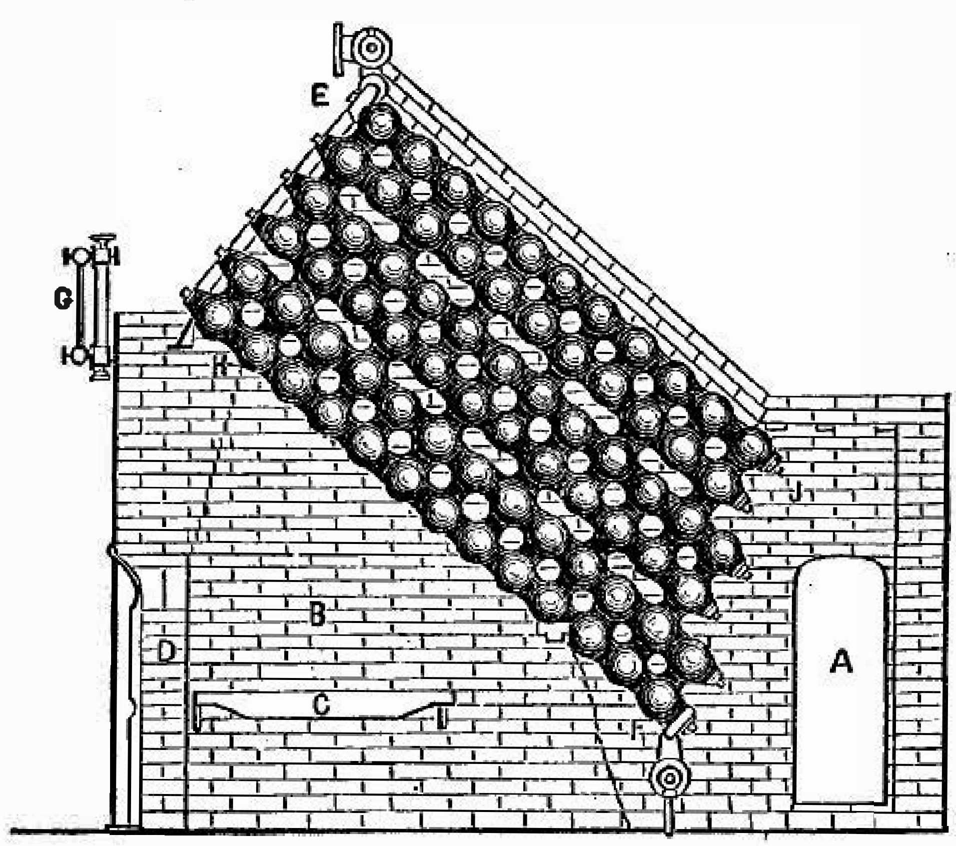


FIG. 111.—Harrison's Sectional Boiler.

and fitted together with faced joints. Long bolts, extending from end to end of each row, bind the spheres together. (*See* Fig. 111.)

An example of another modern type in extensive use is given in Fig. 112, a semi-sectional boiler, which consists of a series of inclined wrought-iron tubes, connected by T-heads, which form the vertical water-channels, at each end. The joints are faced by milling them, and then ground so perfectly tight that a pressure of 500 pounds to the square inch is insufficient to produce leakage.n No packing is used.

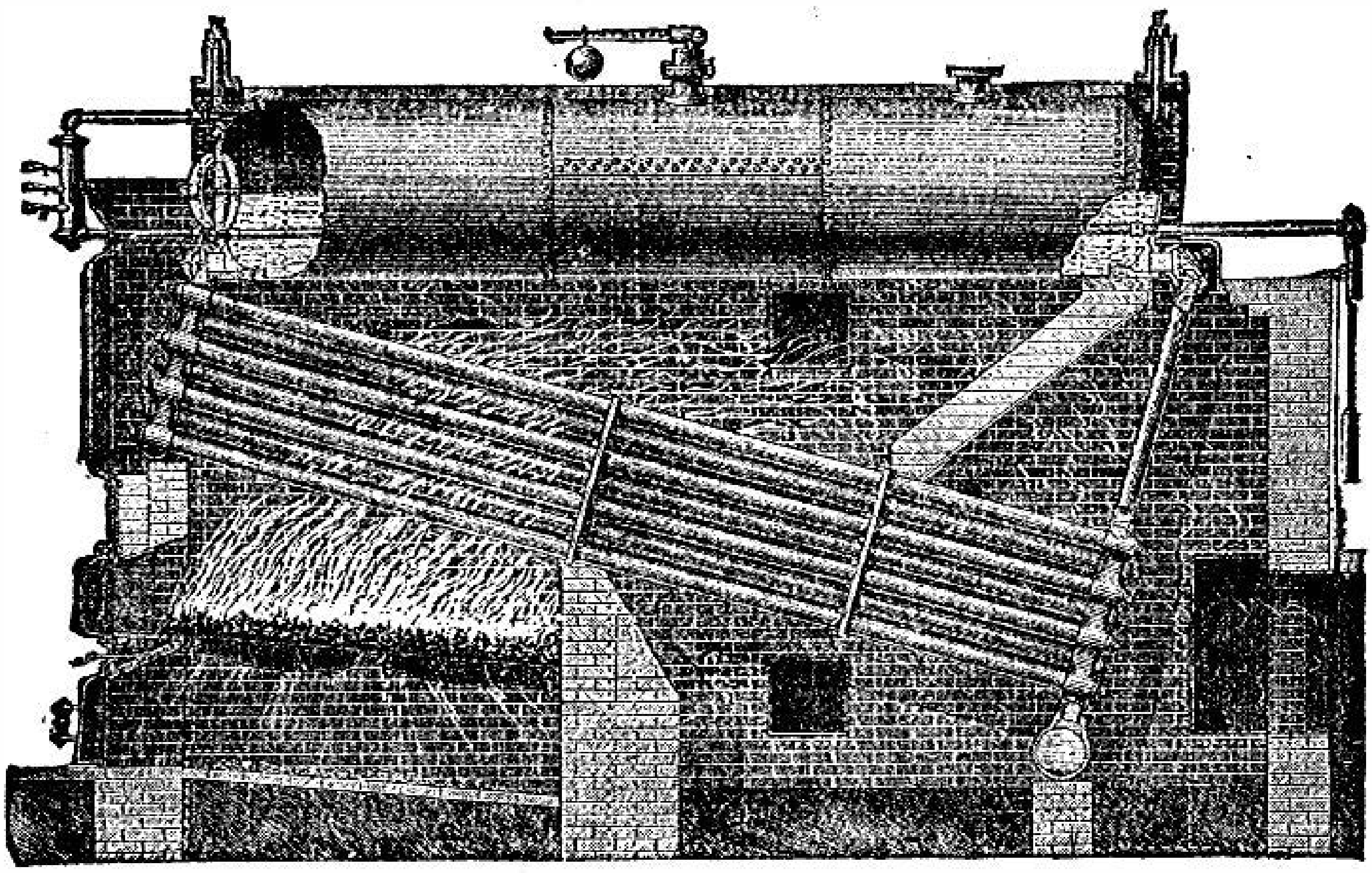


FIG. 112.—Babcock and Wilcox's Sectional Boiler.

The fire is made under the front and higher end of the tubes, and the products of combustion pass up between the tubes into a combustion-chamber under the steam and water drum ; hence they pass down between the tubes, then once more up through the space between the tubes, and off to the chimney. The steam is taken out at the top of the steam-drum near the back end of the boiler. The rapid circulation prevents to some extent the formation of deposits or incrustations upon the heating-surfaces, sweeping them away and depositing them in the mud-drum, whence they are blown out. Rapid circulation of water,nas has been shown by Prof. Trowbridge, also assists in the extraction of the heat from the gases, by the presentation of fresh water continually, as well as by the prevention of incrustation.

Attempts have been made to adapt sectional boilers to marine engines ; but very little progress has yet been made

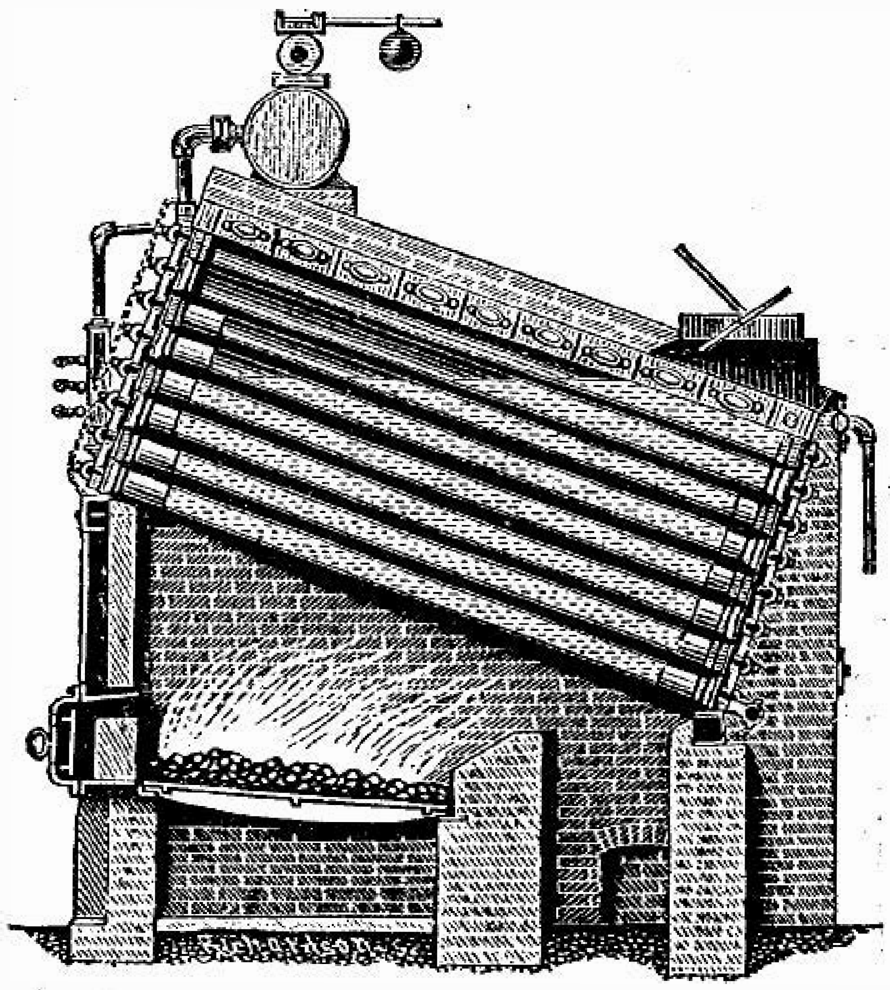


FIG. 113.—Root Sectional Boiler.

in their introduction. The Root sectional boiler (Fig. 113), an American design, which is in extensive use in the United States and Europe, has also been experimentally placed in service on shipboard. Its heating surface consists mainly of tubes, which are connected by a peculiarly formed series of caps. In recent forms a series of steam and water drums give increased efficiency.

SECTION II.—PORTABLE AND LOCOMOTIVE ENGINES.

Engines and boilers, when of small size, are now often combined in one structure which may be readily transported. Where they have a common base-plate simply, as in Fig. 114, they are called, usually, "semi-portable engines." These little engines have some decided advantages. Being attached to one base, the combined engine and boiler is easily transported, occupies little space, and may very readily be mounted upon wheels, rendering it peculiarly well adapted for agricultural purposes.

The example here shown differs in its design from those usually seen in the market. The engine is not fastened to or upon the boiler, and is therefore not affected by expan-

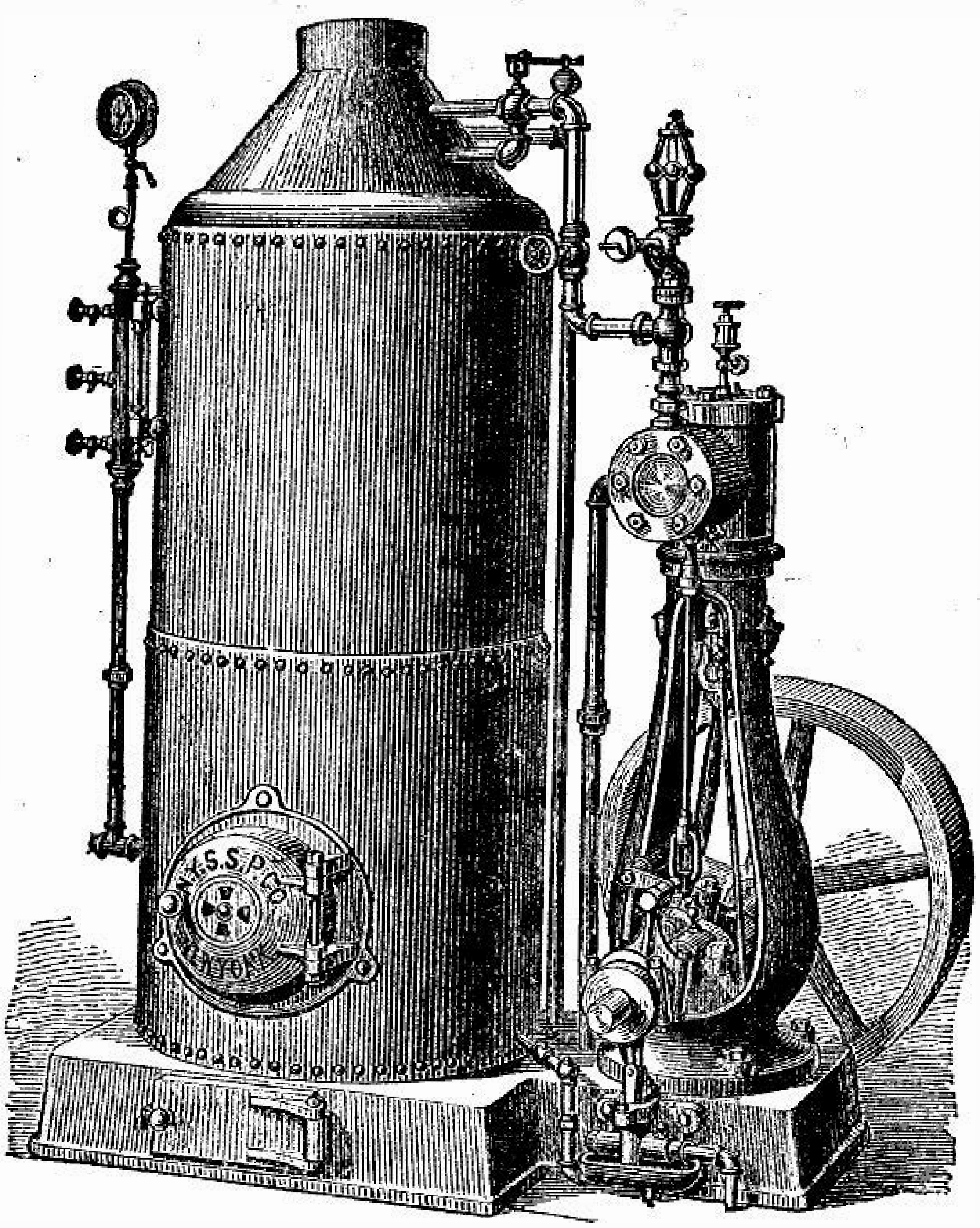


FIG. 114.—Semi-Portable Engine, 1878.

sion, nor are the bearings overheated by conduction or by ascending heat from the boiler. The fly-wheel is at the base, which arrangement secures steadiness at the high speed which is a requisite for economy of fuel. The boilers are of the upright tubular style, with internal fire-box, and are intended to be worked at 150 pounds pressure per inch. They are fitted with a baffle-plate and circulating-pipe, to prevent priming, and also with a fusible plug, which will melt and prevent the crown-sheet of the boiler burning, if the water gets low.

Another illustration of this form of engine, as built in small sizes, is seen below. The peculiarity of this engine

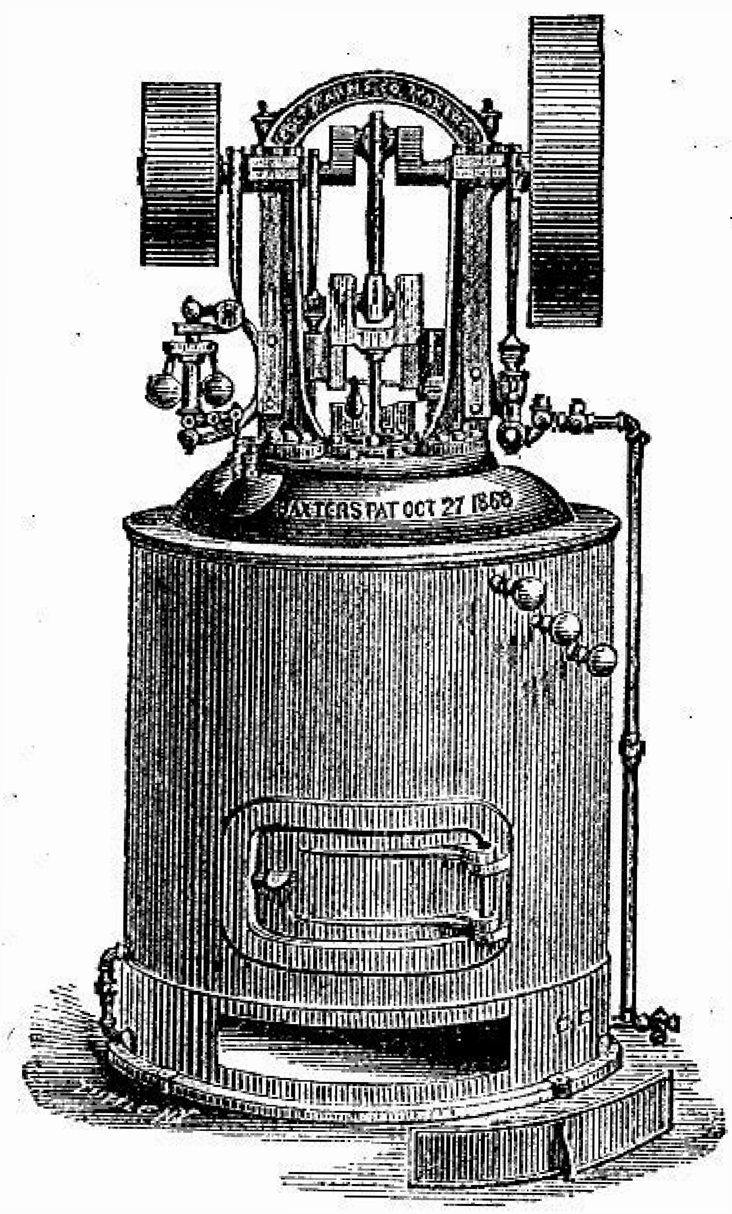


FIG. 115.—Semi-Portable Engine, 1878.

is, that the cylinder is placed in the top of the boiler, which is upright. By this arrangement the engine is constantly drawing from the boiler the hottest and driest steam, and there is thus no liability of serious loss by condensation, which is rapid, even in a short pipe, when the engine is separate from the boiler.

The engine illustrated is rated at 10 horse-power, and makers are always expected to guarantee their machines to work up to the rated power. The cylinder is 7 by 7 inches, and the main shaft is directly over it. On this shaft are three eccentrics, one working the pump, one moving the valves, and the third one operating the cut-off.n The driving-pulley is 20 inches in diameter, and the balance-wheel 30 inches. The boiler has 15 1¼-inch flues. It is furnished with a heater in its lower portion. The boiler of this engine is tested up to 200 pounds, and is calculated to carry 100 pounds working pressure, though that is not necessary to develop the full power of the engine. The compactness of the whole machine is exceptional. It can be set up in a space 5 feet square and 8 feet high. The weight of the 10 horse-power engine is 1,540 pounds, and of the whole machine 4,890 pounds, boxed for shipment. Every part of the mechanism usually fits and works with the exactness of a gun-lock, as each piece is carefully made to gauge.

Portable engines are those which are especially intended to be moved conveniently from place to place. The engine is usually attached to the boiler, and the feed-pump is generally attached to the engine. The whole machine is carried on wheels, and is moved from one place to another, usually by horses, but sometimes by its own engine, which is coupled by an engaging and disengaging apparatus to the rear-wheels. English builders have usually excelled in the construction of this class of steam-engine, although it is probable that the best American engines are fully equal to them in design, material, and construction.

The later work of the best-known English builders has given economical results that have surprised engineers. The annual "shows" of the Royal Agricultural Society have elicited good evidence of skill in management as well as of excellence of design and construction. Some little portable engines have exhibited an economical efficiency superior to that of the largest marine engines of any but the compound type, and even closely competing with that form. The causes of this remarkable economy are readily learned by an inspection of these engines, and by observation of the method of managing them at the test-trial. The engines are usually very carefully designed. The cylinders are nicely proportioned to their work, and their pistons travel at high speed. Their valve-gear consists usually of a plain slide-valve, supplemented by a separate expansion-slide, driven by an independent eccentric, and capable of considerable variation in the point of cut-off. This form of expansion-gear is very effective—almost as much so as a drop cut-off—at the usual grade of expansion, which is not far from four times. The governor is usually attached to a throttle-valve in the steam-pipe, an arrangement which is not the best possible under variable loads, but which produces no serious loss of efficiency when the engine is driven, as at competitive trials, under the very uniform load of a Prony strap-brake and at very nearly the maximum capacity of the machine. The most successful engines have had steam-jacketed cylinders — always an essential to maximum economy—with high steam and a considerable expansion. The boilers are strongly made, and are, as are also all other heated surfaces, carefully clothed with non-conducting material, and well lagged over all. The details are carefully proportioned, the rods and frames are strong and well secured together, and the bearings have large rubbing-surfaces. The connecting-rods are long and easy-working, and every part is capable of doing its work without straining and with the least friction.

In handling the engines at the competitive trial, most experienced and skillful drivers are selected. The difference between the performances of the same engine in different hands has been found to amount to from 10 to 15 per cent., even where the competitors were both considered exceptionally skillful men. In manipulating the engine, the fires are attended to with the utmost care; coal is thrown upon them at regular and frequent intervals, and a uniform depth of fuel and a perfectly clean fire are secured. The sides and corners of the fire are looked after with especial care. The fire-doors are kept open the least possible time; not a square inch of grate-surface is left unutilized, and every pound of coal gives out its maximum of calorific power, and in precisely the place where it is needed. Feed-water is supplied as nearly as possible continuously, and with the utmost regularity. In some cases the engine-driver stands by his engine constantly, feeding the fire with coal in handfuls, and supplying the water to the heater by hand by means of a cup. Heaters are invariably used in such cases. The exhaust is contracted no more than is absolutely necessary for draught. The brake is watched carefully, lest irregularity of lubrication should cause oscillation of speed with the changing resistance. The load is made the maximum which the engine is designed to drive with economy. Thus all conditions are made as favorable as possible to economy, and they are preserved as invariable as the utmost care on the part of the attendant can make them.

These trials are usually of only three or five hours' duration, and thus terminate before it becomes necessary to clean fires. The following are results obtained at the trial of engines which took place in July, 1870, at the Oxford Agricultural Fair:

MAKERS' NAME AND RESIDENCE.	CYLINDERS.		Stroke.	HORSE-POWER.		Point of cut-off.	Revolutions per minute.	Pounds coal per horse-power per hour.
	Number.	Diameter.		Nominal.	Dynamometric.			
		Inches.	In.					
Clayton, Shuttleworth & Co., Lincoln....	1	7	12	4	4.42	.....	121.65	3.73
Brown & May, Devizes	1	7 3-16	12	4	4.19	11.48	125.65	4.44
Reading Iron-Works Company, Reading.	1	5 3-4	14	4	4.16	.....	145.7	4.65

These were horizontal engines, attached to locomotive boilers.

At a similar exhibition held at Bury, in 1867, considerably better results even than these were reported, as below, from engines of similar size and styles :

MAKERS' NAME AND RESIDENCE.	CYLINDERS.		Stroke.	HORSE-POWER.		Point of cut-off.	Revolutions per minute.	Pounds coal per horse-power per hour.
	Number.	Diameter.		Nominal	Dynamometric.			
		Inches.	In.					
Clayton, Shuttleworth & Co., Lincoln..e..	1	10	20	10	11.00	3.10	71.5	4.13
Reading Iron-Works Company, Reading.	1	8 5-8	20	10	10.43	1.4	109.4	4.22

With all these engines steam-jackets were usedn the feed-water was highly and uniformly heated by exhaust-steam ; the coal was selected, finely broken, and thrown on the fire with the greatest care ; thenvelocity of the engines, the steam-pressure, and the amount of feed-water, were very carefully regulated, and allnbearings were run quite loose ; the engine-drivers were usually expert "jockeys."

The next illustration represents the portable steam-engine as built by one of the oldest and most experienced manufacturers of such engines in the United States.

In the boilers of these engines the heating-surface is given less extent than in the stationary engine-boiler, but much greater than in the locomotive, and varies from 10 to 20 square feet per horse-power. The boilers are made very strong, to enable them to withstand the strains due to the attached engine, which are estimated as equivalent to from one-tenth to one-fifth that due to the steam-pressure. The boiler is sometimes given even double the strength usual with stationary boilers of similar capacity. The engine is mounted, in this example, directly over the boiler, and all parts are in sight and readily accessible to the engineer.

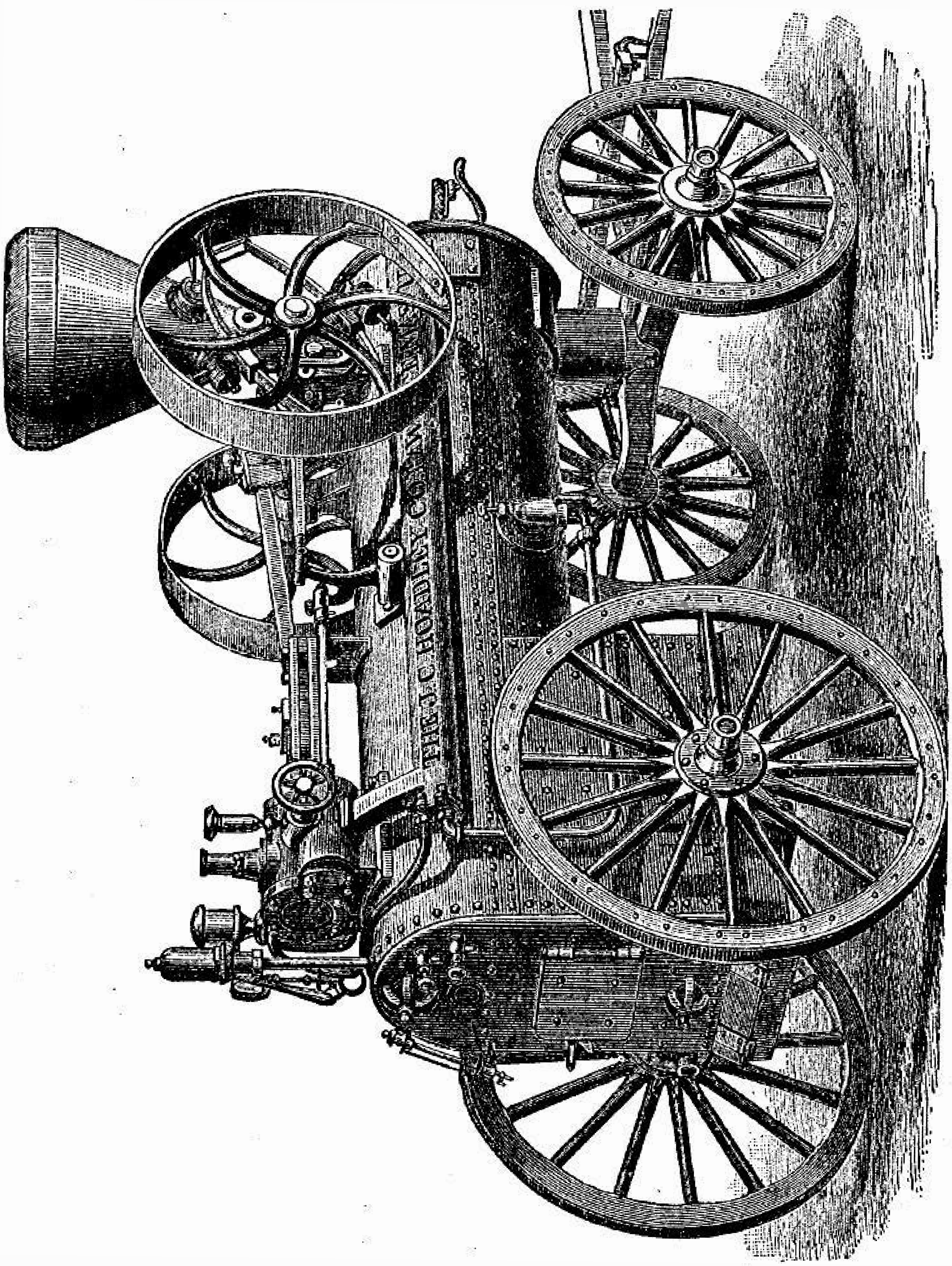


FIG. 116.—The Portable Steam-Engine, 1878.

One of these engines, of 20 horse-power, has a steam-cylinder 10 inches in diameter and 18 inches stroke of piston, making 125 revolutions per minute, and has 9 square feet of grate-surface and 288 feet of heating-surface. It weighs about $4\frac{1}{2}$ tons. Steam is carried at 125 pounds.

In the class of engines just described, the draught is obtained by the blast of the exhaust-steam which is led into the chimney. Such engines are now sold at from $120 to $150 per horse-power, according to size and quality, the smaller engines costing most. The usual consumption of

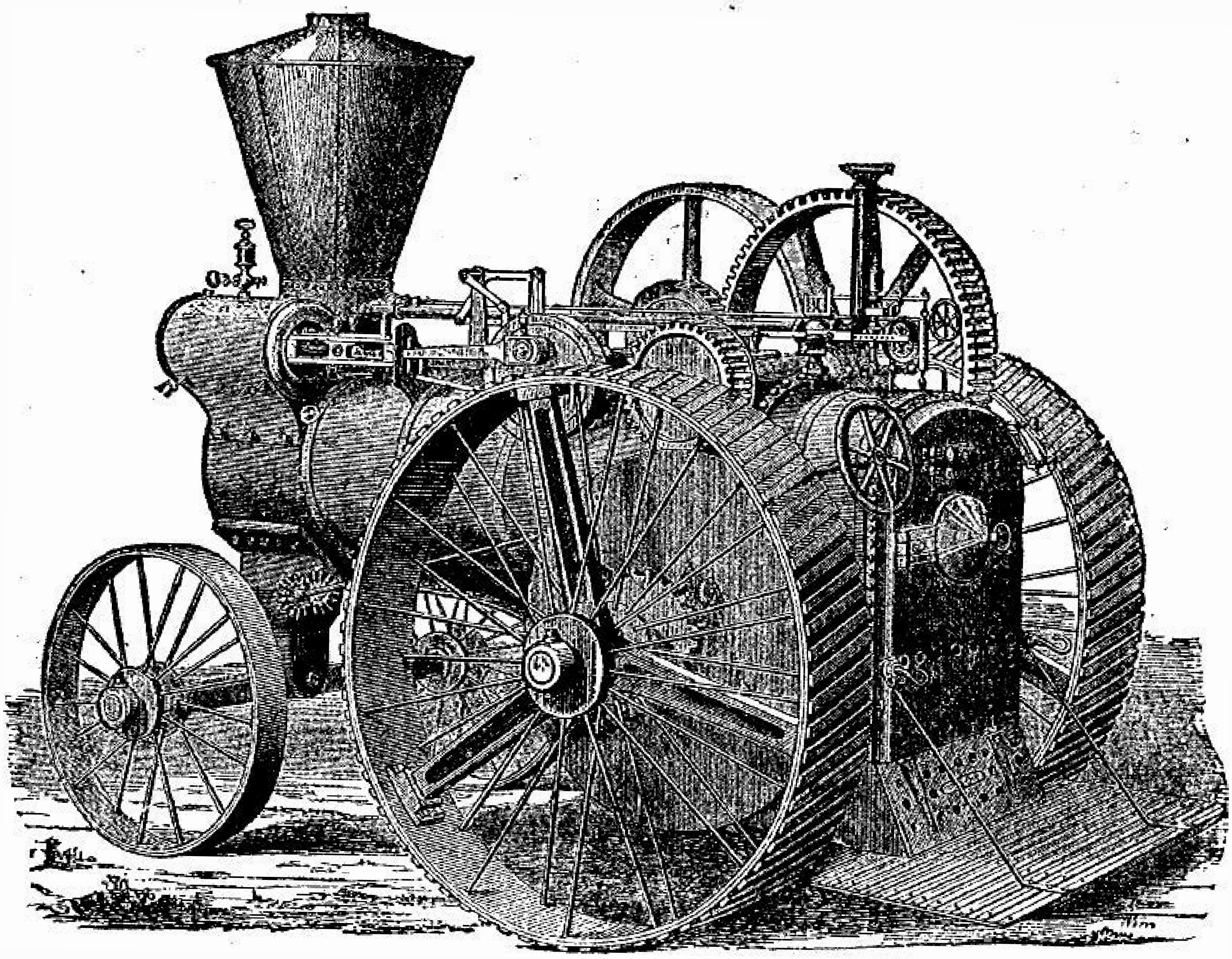


FIG. 117.—The Thrashers' Road-Engine, 1878.

fuel is from 4 to 6 pounds per hour and per horse-power, burning from 15 to 20 pounds on each square foot of grate, and each poundeevaporating about 8 pounds of water. A usual weight is, for the larger sizes, 500 pounds per horse-power.

These engines are sometimes arranged to propel themselves, as in the Mills "Thrashers'ri' road-engine or locomotive, of which the accompanying engraving is a good representation. This engine is proportioned for hauling a tank containing 10 barrels, or more, of water and a grain-separator over all ordinary roads, and to drive a thrashing-machine or saw-mill, developing 20 or 25 horse-power. This example of the road-engine has a boiler built to work at 250 pounds of steam; the engine is designed for a maximum power of 30 horses.

This engine has a balanced valve and automatic cut-off, and is fitted with a reversing-gear for use on the road. The driving-wheels are of wrought-iron, 56 inches diameter and 8 inches wide, with cast-iron driving-arms. Both wheels are driversnon curves as well as on straight lines. The engine is guided and fired by one man, and the total weight is so small that it will pass safely over any good country bridge. A brake is attached, to insure safety when going down-hill. Although designed to move at a speed of about three miles per hour, the velocity of the piston may be increased so that four miles per hour may be accomplished when necessary.

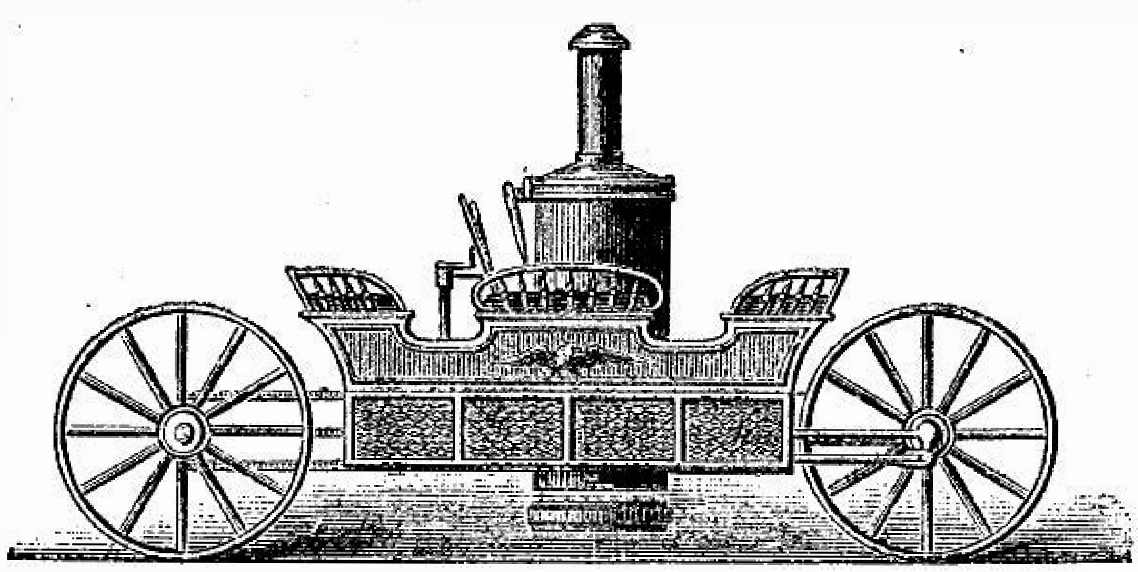


FIG. 118.—Fisher's Steam-Carriage.

This is an excellent example of this kind of engine as constructed at the present time. The strongly-built boiler, with its heater, the jacketed cylinder, and light, strong frame of the engine, the steel running-gear, the carefullycovered surfaces of cylinder and boiler, and excellent proportions of details, are illustrations of good modern engineering, and are in curious contrast with the first of the class, built a century earlier by Smeaton.

Steam-carriages for passengers are now rarely built. Fig. 118 represents that designed by Fisher about 1870 or earlier. It was only worked experimentally.

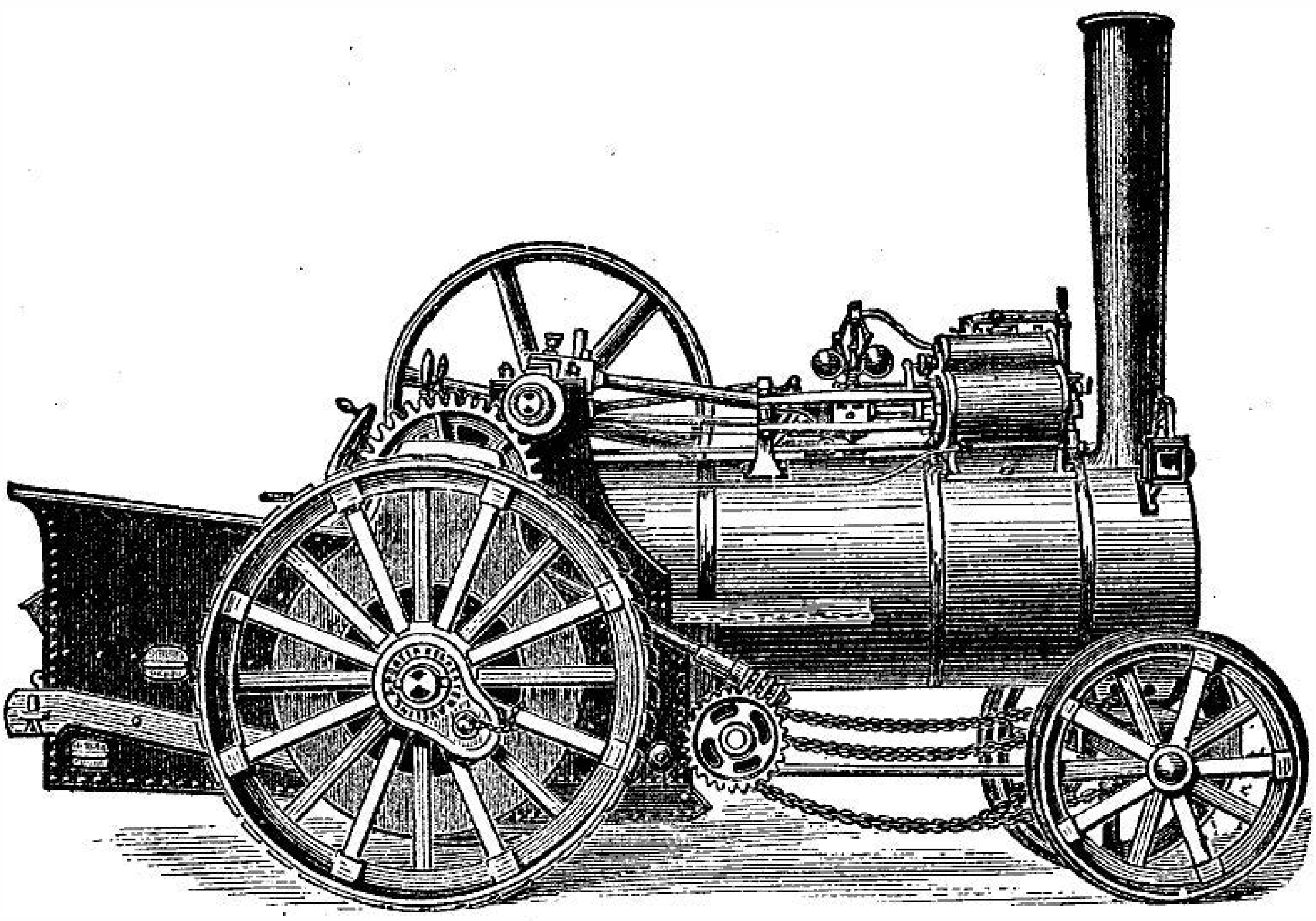


FIG. 119.—Road and Farm Locomotive.

The above is annengraving of a road and farm locomotive asnbuilt by one of the most successful among several British firms engaged in this work.

The capacity of these engines has been determined by experiment by the author in the United States, and abroad by several distinguished engineers.

The author made a trial of one of these engines at South Orange, N. J., to determine its power, speed, and convenience of working and manœuvring. The following were the principal dimensions :

Weight of engine, complete, 5 tons 4 cwt.	11,648	pounds.
Steam-cylinder—diameter	$7\frac{3}{4}$	inches.
Stroke of piston	10	inches.
Revolution of crank to one of driving-wheels. . . .	17	
Driving-wheels—diameter	60	inches.
" breadth of tire	10	inches.
" weight, each	450	pounds.
Boiler—length over all	8	feet.
" diameter of shell	30	feet.
" thickness of shell	$\frac{7}{16}$	inch.
" fire-box sheets, outside, thickness.	$\frac{1}{2}$	inch.
Load on driving-wheels, 4 tons 10 cwt.	10,080	pounds.

The boiler was of the ordinary locomotive type, and the engine was mounted upon it, as is usual with portable engines.

The steam-cylinder was steam-jacketed, in accordance with the most advanced practice here and abroad. The crank-shaft and other wrought-iron parts subjected to heavy strains were strong and plainly finished. The gearing was of malleableized cast-iron, and all bearings, from crank-shaft to driving-wheel, on each side, were carried by a single sheet of half-inch plate, which also formed the sides of the fire-box exterior.

The following is a summary of the conclusions deduced by the author from the trial, and published in the *Journal of the Franklin Institute:* A traction-engine may be so constructed as to be easily and rapidly manœuvred on the common road; and an engine weighing over 5 tons may be turned continuously without difficulty on a circle of 18 feet radius, or even on a road but little wider than the length of the engine. A locomotive of 5 tons 4 hundred-weight has beennconstructed, capable of drawing on a good road 23,000 pounds up a grade of 533 feet to the mile, at the rate of four miles an hour; and one might be constructed to draw more than 63,000 pounds up a grade of 225 feet to the mile, at the rate of two miles an hour.

It was further shown that the coefficient of traction with heavily-laden wagons on a good macadamized road is not far from .04; the traction-power of this engine is equal to that of 20 horses; the weight, exclusive of the weight of the engine, that could be drawn on a level road, was 163,452 pounds; and the amount of fuel required is estimated at 500 pounds a day. The advantages claimed for the traction-engine over horse-power are: no necessity for a limitation of working-hours; a difference in first cost in favor of steam; and in heavy work on a common road the expense by steam is less than 25 per cent. of the average cost of horse-power, a traction-engine capable of doing the work of 25 horses being worked at as little expense as 6 or 8 horses. The cost of hauling heavy loads has been estimated at 7 cents per ton per mile.

Such engines are gradually becoming useful in steam-ploughing. Two systems are adopted. In the one the engine is stationary, and hauls a "gang" of ploughs by means of a windlass and wire rope; in the other the engine traverses a field, drawing behind it a plough or a gang of ploughs. The latter method has been proposed for breaking up prairie-land.

Thus, thirty years after the defeat of the intelligent, courageous, and persistent Hancock and his coworkers in the scheme of applying the steam-engine usefully on the common road, we find strong indications that, in a new form, the problem has been again attacked, and at least partially solved.

One of the most important of the prerequisites to ultimate success in the substitution of steam for animal power on the highway is that our roads shall be well made. As the greatest care and judgment are exercised, and an immense outlay of capital is considered justifiable, in securing easy grades and a smooth track on our railroad routes, we may readily believe that similar precaution and outlay will be found advisable in adapting the common road to the road-locomotive. It would seem to the engineer that the natural obstacles generally supposed to stand in the way have, after all, no real existence. The principal inconvenience that may be anticipated will probably arise from the carelessness or avarice of proprietors, which may sometimes cause them to appoint ignorant and inefficient engine-drivers, giving them charge of what are always excellent servants, but terrible masters. Nevertheless, as the transportation of passengers on railroads is found to be attended with less liability to loss of life or injury of person than their carriage by stage-coach, it will be found, very probably, that the general use of steam in transporting freight on common roads may be attended with less risk to life or property than to-day attends the use of horse-power.

The STEAM FIRE-ENGINE is still another form of portable engine. It is also one of the latest of all applications of steam-power. The steam fire-engine is peculiarly an American production. Although previously attempted, their permanently successful introduction has only occurred within the last fifteen years.

As early as 1830, Braithwaite and Ericsson, of London, England, built an engine with steam and pump cylinders of 7 and $6\frac{1}{2}$ inches diameter, respectively, with 16 inches stroke of piston. This machine weighed $2\frac{1}{2}$ tons, and is said to have thrown 150 gallons of water per minute to a height of between 80 and 100 feet. It was ready for work in about 20 minutes after lighting the fire. Braithwaite afterward supplied a more powerful engine to the King of Prussia, in 1832. The first attempt made in the United States to construct a steam fire-engine was probably that of Hodge, who built one in New York in 1841. It was a strong and very effective machine, but was far too heavy for rapid transportation. The late J. K. Fisher, who throughout his life persistently urged the use of steam-carriages and traction-engines, designing and building several, also planned a steam fire-engine. Two were built from his design by the Novelty Works, New York, about 1860, for Messrs. Lee & Larned.

They were "self-propellers," and one of them, built for the city of Philadelphia, was sent to that city over the highway, driven by its own engines. The other was built for and used

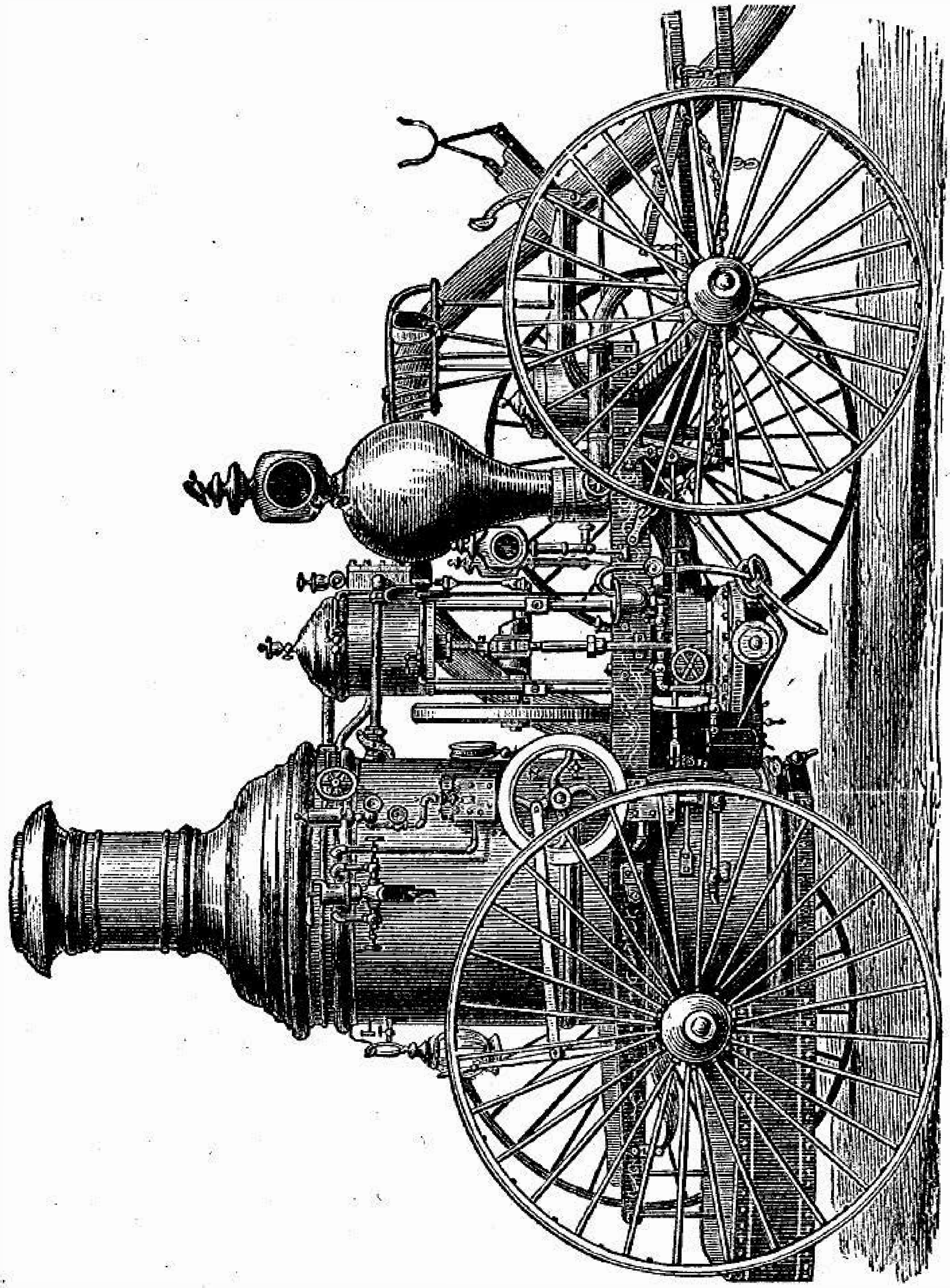


FIG. 120.—The Latta Steam Fire-Engine.

by the New York Fire Department, and did good service for several years. These engines were heavy, but very powerful, and were found to move at good speed under steam and to manœuvre well. The Messrs. Latta, of Cincinnati, soon after succeeded in constructing comparatively light and very effective engines, and the fire department of that city was the first to adopt steam fire-engines definitely as their principal reliance. This change has now become general.

The steam fire-engine has now entirely displaced the old hand-engine in all large cities. It does its work at a fraction of the cost of the latter. It can force its water to a height of 225 feet, and to a distance of more than 300 feet horizontally, while the hand-engine can seldom throw it one-third these distances; and the "steamer" may be relied upon to work at full power many hours if necessary, while the men at the hand-engine soon become fatigued, and require frequent relief. The city of New York has 40 steam fire-engines. One engine to every 10,000 inhabitants is a proper proportion.

In the standard steam fire-engine (Fig. 120) reciprocating engines and pumps are adopted, as seen in section in Fig. 121, in which *A* is the furnace, and *B* the set of closely-set vertical fire-tubes in the boiler. *C* is the combustion-chamber, *D* the smoke-pipe, and *R* the steam-space. *E* is the steam-cylinder, and *F* the pump, which is seen to be double-acting. There are two pairs of engines and pumps, working on cranks, set at right angles, and turning a balance-wheel seen behind them. *G* is the feed-pump which supplies water to the boiler, *H* the air-chamber which equalizes the water-pressure, which reaches it through the pipe, *I J*. *K* is the feed-water tank, under the driver's seat, *L*, which, with the engines and boiler, are carried on the frame, *M M*. The fireman stands on the platform, *N*. When it is necessary to move the machine, an endless chain connects the crank-shaft with the rear-wheels, and the engine, with pumps shut off, is thus made to drive the wheels at any desired speed.

A self-propelling engine by the Amoskeag Company had the following dimensions and performance: Weight, 4 tons; speed, 8 miles per hour; steam-pressure, 75 pounds per square inch; height of stream from $1\frac{1}{4}$-inch nozzle, 225 feet; $1\frac{3}{4}$-inch nozzle, 150 feet; distance horizontally, $1\frac{1}{4}$-

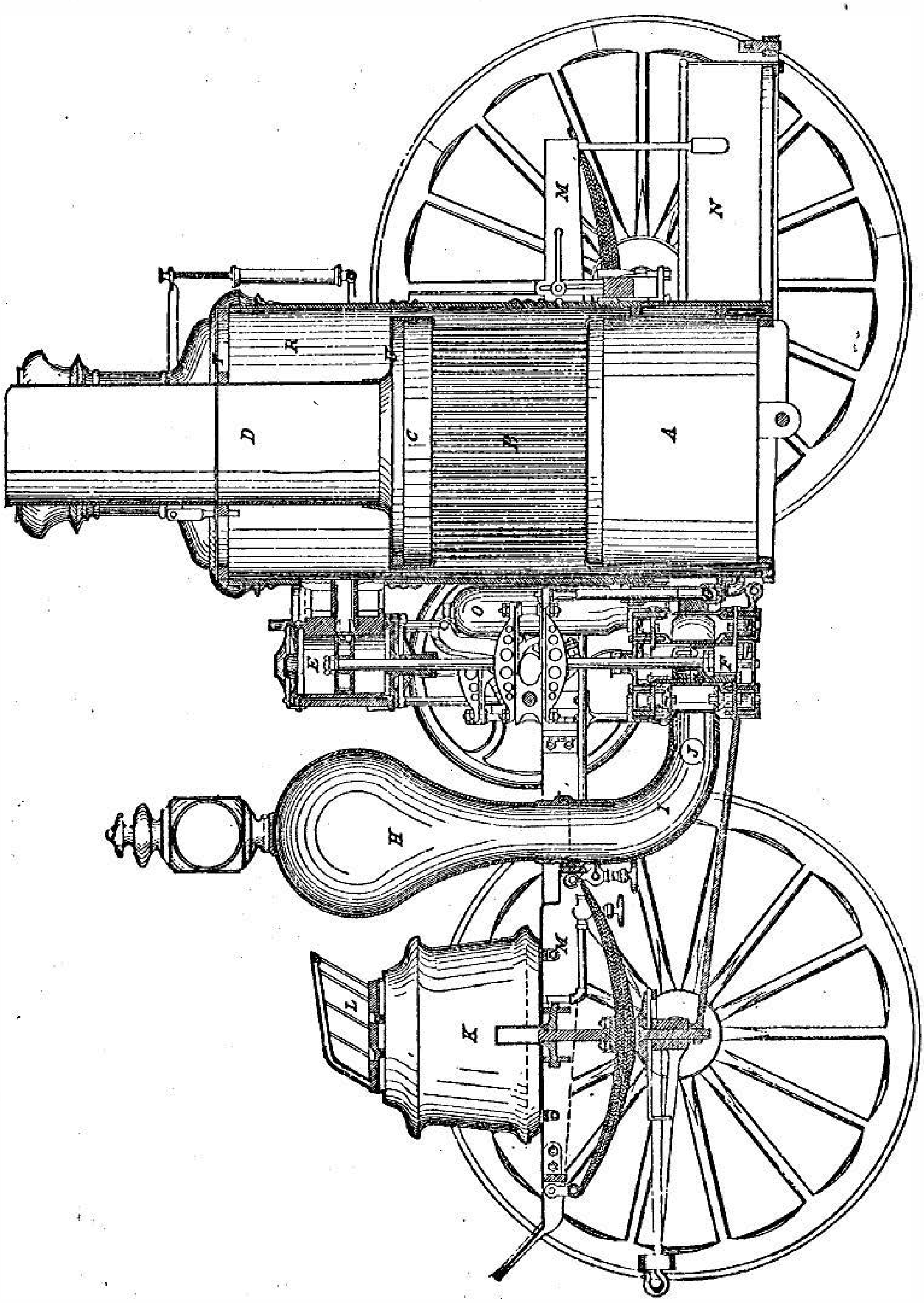


Fig. 121.—The Amoskeag Engine Section.

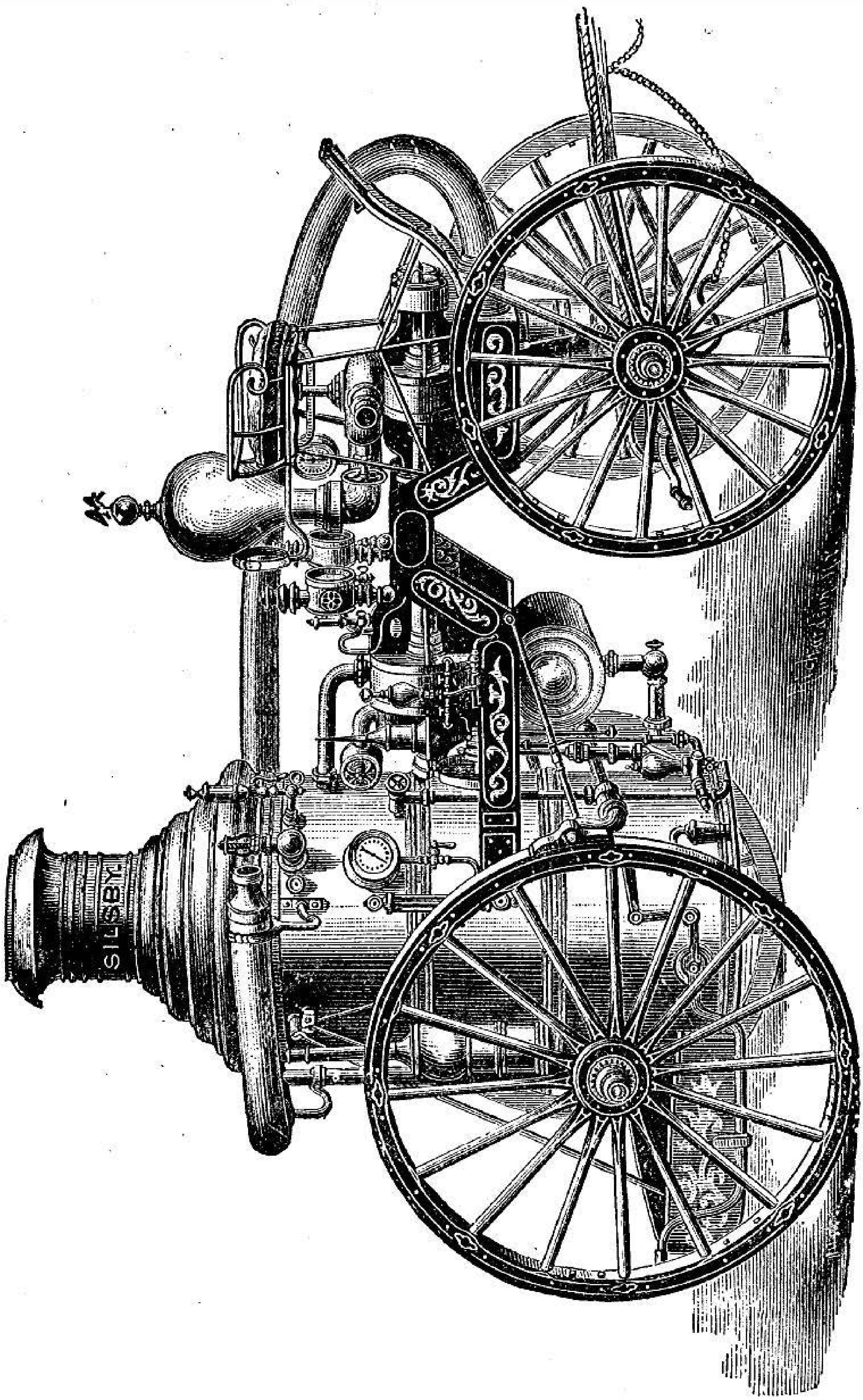


Fig. 122.—The Silsby Rotary Steam Fire-Engine.

inch nozzle, 300 feet; $1\frac{3}{4}$-inch, 250 feet—a performance which contrasts wonderfully with that of the hand-worked fire-engine which these engines have now superseded.

It has recently become common to construct the steam fire-engine with rotary engine and pump (Fig. 122). The superiority of a rotary motion for a steam-engine is apparently so evident that many attempts have been made to overcome the practical difficulties to which it is subject. One of these difficulties, and the principal one, has been the packing of the part which performs the office of the piston in the straight cylinder. Robert Stephenson once expressed the opinion that a rotary engine would never be made to work successfully, on account of this difficulty of packing. The most palpable of the advantages of the rotary engine are the reduction in the size of the engine, claimed to result from the great velocity of the piston; the avoidance of great accidental strains, especially noticed in propelling ships; and a great saving of the power which is asserted to be expended in the reciprocating engine in overcoming the inertia while changing the direction of the motions. These advantages adapt the rotary engine, in an especial manner, to the driving of a locomotive or steam fire-engine.

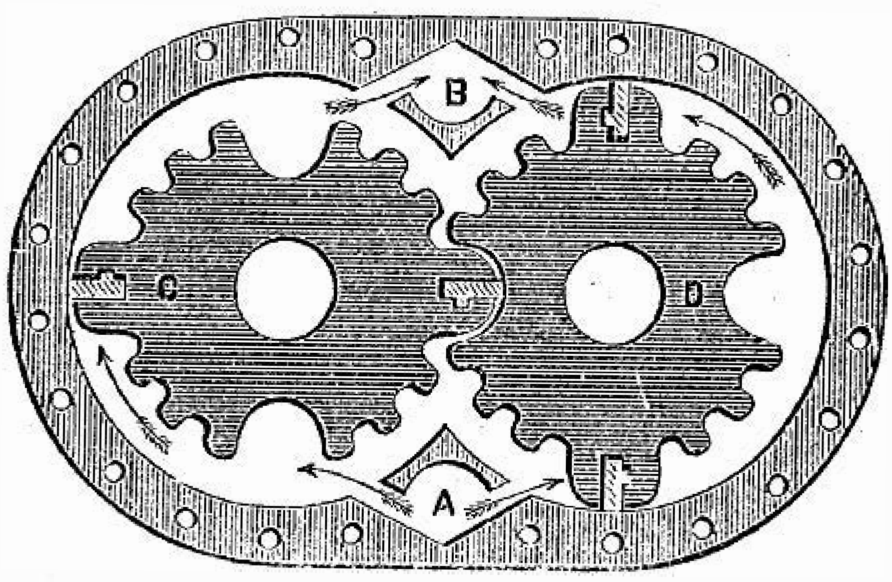


FIG. 123.—Rotary Steam-Engine.

In the Holly rotary engine, seen in Fig. 123, eccentrics and sliding-cams, which are frequently used in rotary engines, and which are objectionable on account of their great friction, are avoided. Corrugated pistons, or irregular cams, *C D*, are adopted, forming chambers within the cases. In the engine the steam enters at *A*, at the bottom of the case, and presses the cams apart. The only packing used is in the ends of the long metal cogs, which are ground to fit the case and are kept out by the momentum of the cams, assisted by a slight spring back of the packing-pieces. The friction on the pump (Fig. 124) is said to be less than in

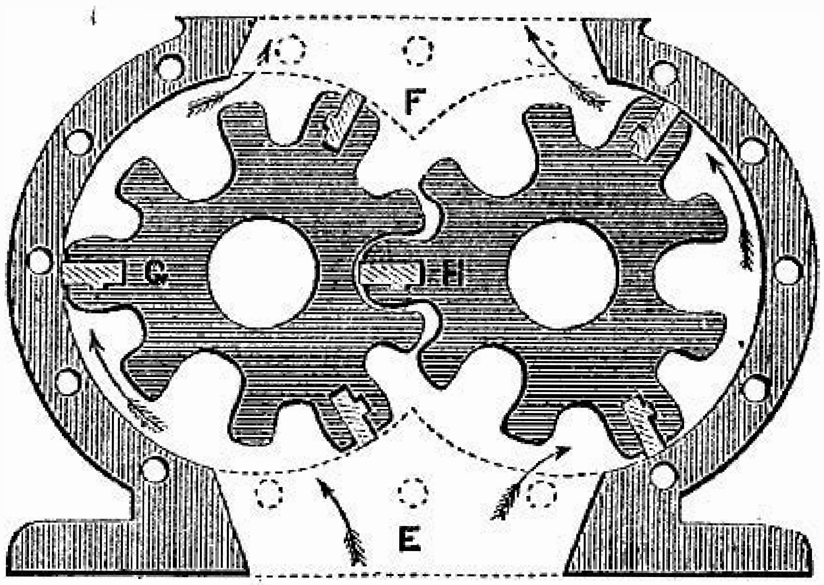


FIG. 124.—Rotary Pump.

the engine. This is the reason given in support of the claim that the rotary engine forces water to a given distance with from one-fourth to one-third the steam-pressure necessary to drive all reciprocating engines. The smaller amount of power necessary to do the work, the less strain and consequent wear and tear upon the whole machine, are said to make it more durable and reliable. The pump being chambered, its liability to injury by the use of dirty or gritty water is lessened, and it is stated that it will last for years, pumping gritty water that would soon cut out a piston-pump. The pump used with this engine is, as shown in the above illustration, somewhat similar to the rotary engine driving it. Each of the revolving pistons has three long teeth bearing against the cylinder, and packed, to prevent leakage, like the engine-cams. They are carried on steel shafts coupled toathe engine-shafts. The water enters at *E* and is discharged at *F*; and the passages are purposely made large in order that sand, chips, and dirt, which may enter with the water, may pass through.

The rotary engine is gradually coming into use for various special purposes, where small power is called for, and where economy of fuel is not important; but it has never yet competed, and may perhaps never in the future compete, with the reciprocating-piston engine where large engines are required, or where even moderate economy of fuel is essential. This form of engine has assumed so little importance, in fact, in the application of the steam-engine, that comparatively little is known of its history. Watt invented a rotary engine, and Yule many years afterward (1836) constructed such engines at Glasgow. Lambapatented another in 1842, Behrens still another in 1847. Napier, Hall, Massey, Holly, La France, and others, have built engines of this class in later times. Nearly all consist either of cams rotating in gear, as in those above sketched, or of a piston set radially in a cylinder of small diameter, which turns on its axis within a much larger cylinder set eccentrically, the piston, as the former turns, sliding in and out of the smaller cylinder as its outer edge slides in contact with the inner surface of the larger. In some forms of rotary engine, a piston revolves on a central shaft, and a sliding abutment in the external cylinder serves to separate the steam from the exhaust side and to confine the steam expanding while doing work. Nearly all of these combinations are also used as pumps.

Fire-engines, made by the best-known American builders of engines, with reciprocating engines and pumps, such as are in general use in the United States, have become standard in general plan and arrangement of details. These are probably the best illustrations of extremea lightness, combined with strength of parts and working power, which have ever been produced in any branch of mechanical engineering. By using a small boiler crowded with heating-surface, very carefully proportioned and arranged, and with small water-spaces; by adopting steel for running-gear and working parts wherever possible; by working at high piston-speed and with high steam-pressure; by selecting fuel with extreme care—by all these expedients, the steam fire-engine has been brought, in this country, to a state of efficiency far superior to anything seen elsewhere. Steam is raised with wonderful promptness, even from cold water, and water is thrown from the nozzle at the end of long lines of hose to great distances. But this combination of lightness with power is only attained at the expense of a certain regularity of action which can only be secured by greater water and steam capacity in the boiler. The small quantity of water contained within the boiler makes it necessary to give constant attention to the feed, and the tendency, almost invariably observed, to serious foaming and priming not only compels unintermitted care while running, but even introduces an element of danger which is not to be despised, even though the machine be in charge of the most experienced and skillful attendants. Even the greatest care, directed by the utmost skill, would not avail to prevent frequent explosions, were it not for the fact that it rarely, if ever, happens that accidents to such boilers occur from low water, unless the boiler is actually completely emptied of water. In driving them at fires, they frequently foam so violently that it is utterly impossible to obtain any clew to the amount of water present, and the attendant usually keeps his feed-pump on and allows the foaming to go on. As long as water is passing into the boiler it is very unlikely that any portion will become overheated and that accident will occur. Such management appears very reckless, and yet accident from such a cause is exceedingly rare.

The changes which have been made in LOCOMOTIVE-CONSTRUCTION during the past few years have also been in the direction of the refinement of the earlier designs, and have been accompanied by corresponding changes in all branches of railroad-work. The adjustment of parts to each other and proportioning them to their work, the modification of the minor details to suit changes of general dimensions, the improvement of workmanship, and the use of better material, have signalized this latest period. Special forms of engine have been devised for special kinds of work. Small, light tank-engines (Fig.n125), carrying their own fuel and water without "tenders," are used for moving cars about terminal stations and for making up trains; powerful, heavy, slow-moving engines, of large boiler-capacity and with small wheels, are used on steep gradients and for hauling long trains laden with coal and heavy merchandise; and hardly less powerful but quite differently proportioned "express"-engines are used for passenger and mail service.

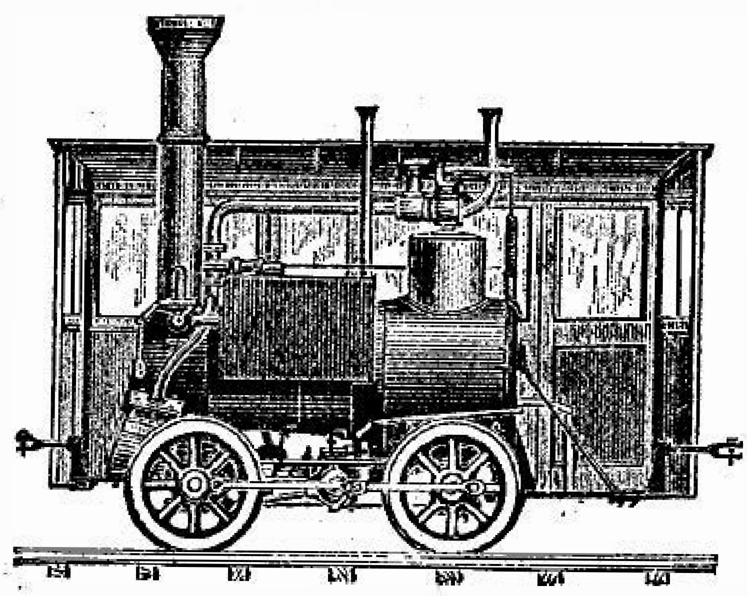


FIG. 125.—Tank-Engine, New York Elevated Railroad.

A peculiar form of engine (Fig. 126) has been designed by Forney, in which the whole weight of engine, tender, coal, and water, is carried by one frame and on one set of wheels, the permanent weight falling on the driving-wheels and the variable load on the truck. These engines have also a comparatively short wheel-basenand high pulling-power. The lightest tank-engines of the first class mentioned weigh 8 or 10 tons; but engines much lighter than these, even, are built for mines, where they are sent into the galleries to bring out the coal-laden wagons. The heaviest engines of this class attain weights of 20 or 30 tons. The

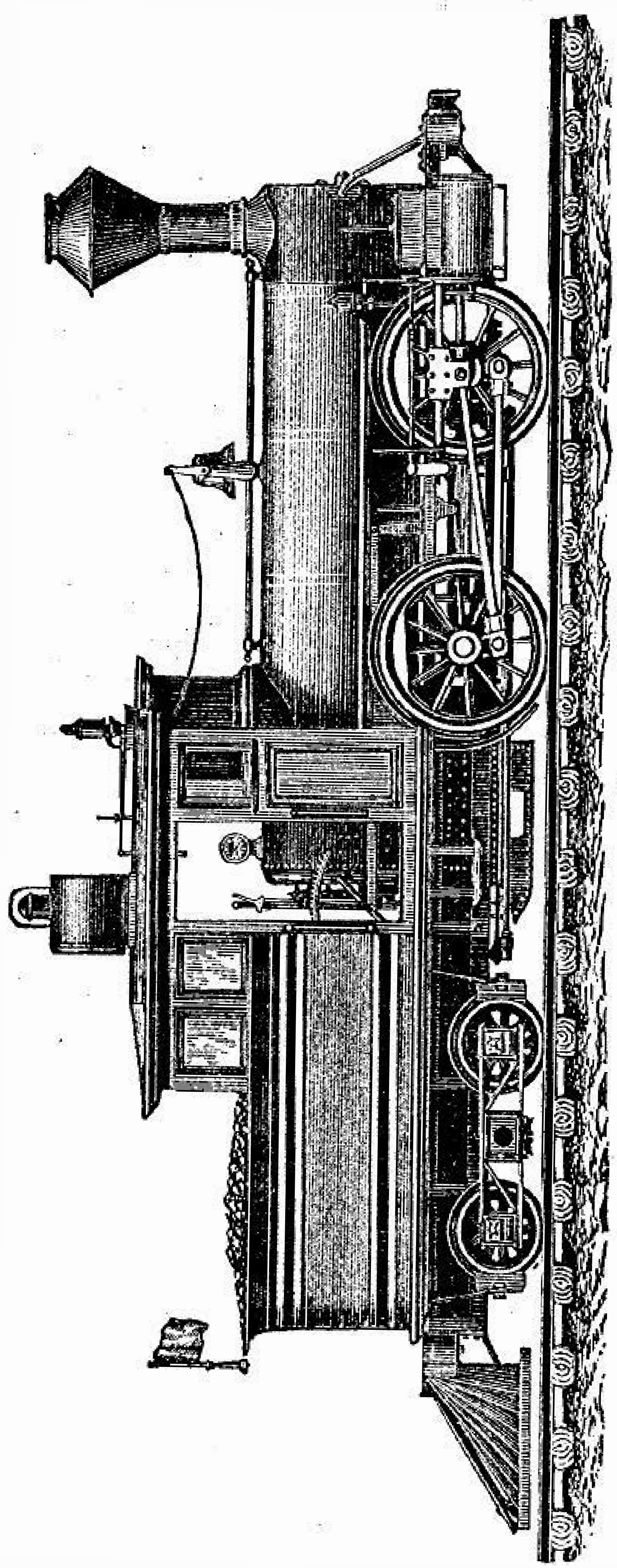


FIG. 126.—Forney's Tank-Locomotive.

heaviest engine yet constructed in the United States is said to be one in use on the Philadelphia & Reading Railroad, having a weight of about 100,000 pounds, which is carried on 12 driving-wheels.

A locomotive has two steam-cylinders, either side by side within the frame, and immediately beneath the forward end of the boiler, or on each side and exterior to the frame. The engines are non-condensing, and of the simplest possible construction. The whole machine is carried upon strong but flexible steel springs. The steam-pressure is usually more than 100 pounds. The pulling-power is generally about one-fifth the weight under most favorable conditions, and becomes as low as one-tenth on wet rails. The fuel employed is wood in new countries, coke in bituminous coal districts, and anthracite coal in the eastern part of the United States. The general arrangement and the proportions of locomotives differ somewhat in different localities. In Fig. 127, a Brit-

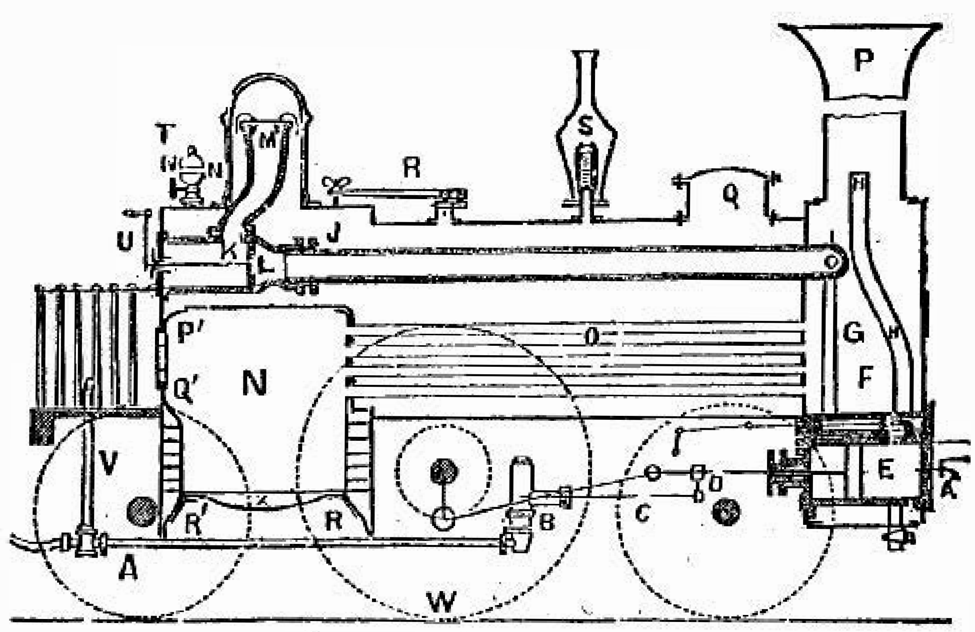


FIG. 127.—British Express Engine.

ish express-engine, *O* is the boiler, *N* the fire-box, *X* the grate, *G* the smoke-box, and *P* the chimney. *S* is a spring and *R* a lever safety-valve, *T* is the whistle, *L* the throttle or regulator valve, *E* the steam-cylinder, and *W* the driving-wheel. The force-pump, *B C*, is driven from the cross-head, *D*. The frame is the base of the whole system, and all other parts are firmly secured to it. The boiler is made fast at one end, and provision is made for its expansion when heated. Adhesion is secured by throwing a proper proportion of the weight upon the driving-wheel, *W.* This is from about 6,000 pounds on standard freight-engines,

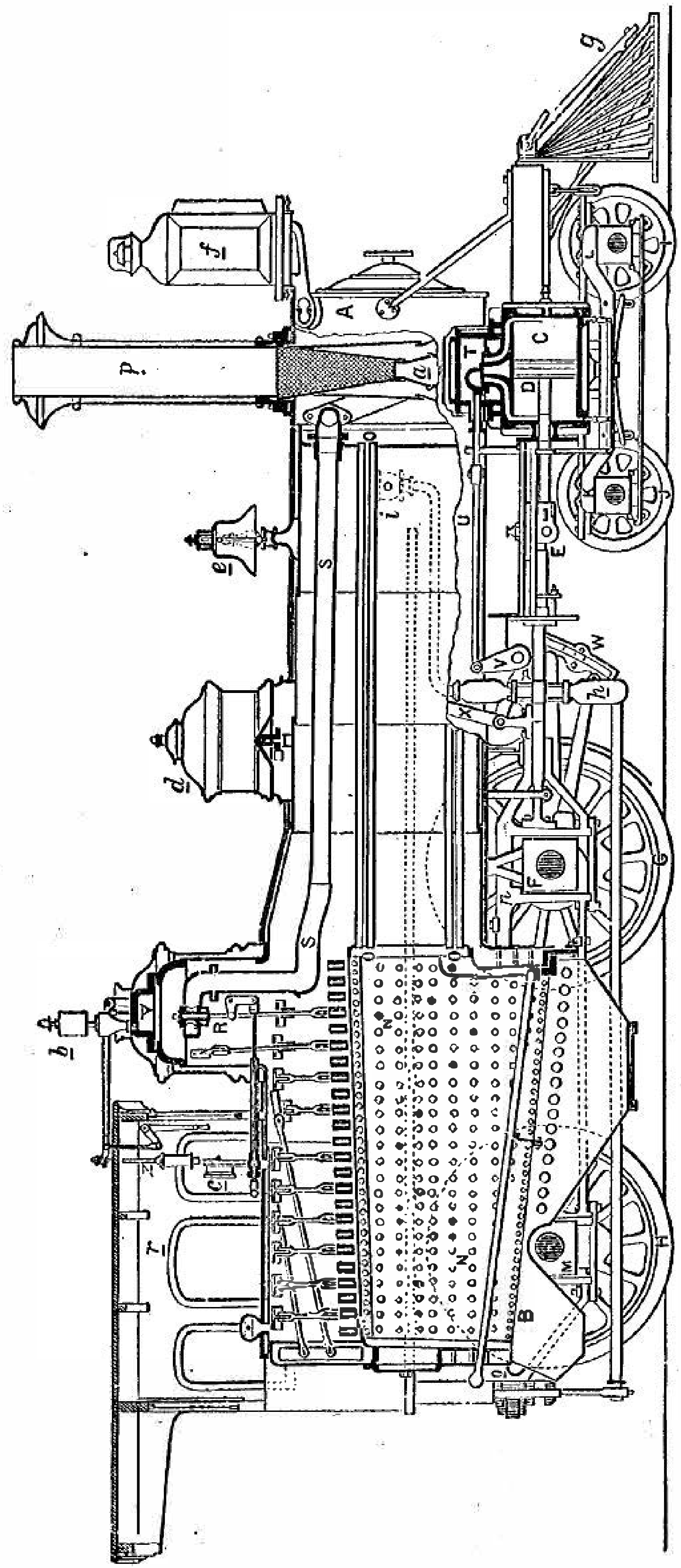


FIG. 128.—The Baldwin Locomotive. Section.

having several pairs of drivers, to 10,000 pounds on passenger-engines, per axle. The peculiarities of the American type (Fig. 128) are the truck, *I J*, or bogie, supporting the forward part of the engine, the system of equalizers, or beams which distribute the weight of the machine equally over the several axles, and minor differences of detail. The cab or house, *r*, protecting the engine-driver and fireman, is an American device, which is gradually coming into use abroad also. The American locomotive is distinguished by its flexibility and ease of action upon even roughly-laid roads. In the sketch, which shows a standard American engine in section, *A B* is the boiler, *C* one of the steam-cylinders, *D* the piston, *E* the cross-head, connected to the crank-shaft, *F*, by the connecting-rod, *G H* the driving-wheels, *I J* the truck-wheels, carrying the truck, *K L*; *M N* is the fire-box, *O O* the tubes, of which but four are shown. The steam-pipe, *R S*, leads the steam to the valve-chest, *T*, in which is seen the valve, moved by the valve-gear, *U V*, and the link, *W*. The link is raised or depressed by a lever, *X*, moved from the cab. The safety-valve is seen at the top of the dome, at *Y*, and the spring-balance by which the load is adjusted is shown at *Z*. At *a* is the cone-shaped exhaust-pipe, by which a good draught is secured. The attachments *b*, *c*, *d*, *e*, *f*, *g*—whistle, steam-gauge, sand-box, bell, head-light, and "cow-catcher"—are nearly all peculiar, either in construction or location, to the American locomotive. The cost of passenger-locomotives of ordinary size is about $10,000; heavier engines sometimes cost $15,000. The locomotive is usually furnished with a tender, which carries its fuel and water. The standard passenger-engine on the Pennsylvania Railroad has four driving-wheels, 5½ feet diameter; steam-cylinders, 17 inches diameter and 2 feet stroke; grate-surface 15½ square feet, and heating-surface 1,058 square feet. It weighs 63,100 pounds, of which 39,000 pounds are on the drivers and 24,100 on the truck. The freight-engine has six driving-wheels, $54\frac{5}{8}$ inches in diameter. The steam-cylinders are 18 inches in diameter, stroke 22 inches, grate-surface 14.8 square feet, heating-surface 1,096 feet. It weighs 68,500

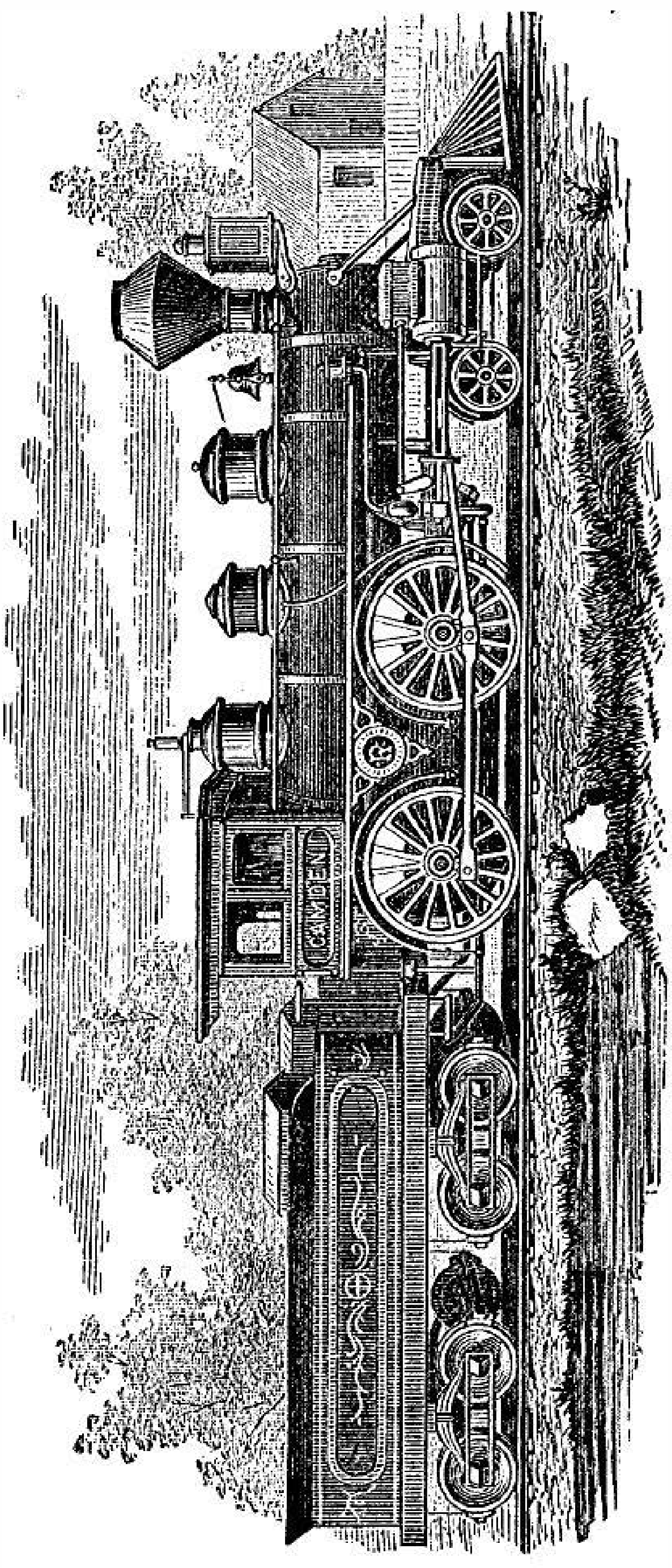


FIG. 129.—The American Type of Express-Engine, 1878.

pounds, of which 48,000 are on the drivers and 20,500 on the truck. The former takes a train of five cars up an average grade of 90 feet to the mile. The latter is attached to a train of 11 cars. On a grade of 50 feet to the mile, the former takes 7 and the latter 17 cars. Tank-engines for very heavy work, such as on grades of 320 feet to the mile, which are found on some of the mountain lines of road, are made with five pairs of driving-wheels, and with no truck. The steam-cylinders are $20\frac{1}{8}$ inches in diameter, 2 feet stroke; grate-area, $15\frac{3}{4}$ feet; heating-surface, 1,380 feet; weight with tank full, and full supply of wood, 112,000 pounds; average weight, 108,000 pounds. Such an engine has hauled 110 tons up this grade at the speed of 5 miles an hour, the steam-pressure being 145 pounds. The adhesion was about 23 per cent. of the weight.

In checking a train in motion, the inertia of the engine itself absorbs a seriously large portion of the work of the brakes. This is sometimes reduced by reversing the engine and allowing the steam-pressure to act in aid of the brakes. To avoid injury by abrasion of the surfaces of piston, cylinder, and the valves and valve-seats, M. Le Châtelier introduces a jet of steam into the exhaust-passages when reversing, and thus prevents the ingress of dust-laden air and the drying of the rubbing surfaces. This method of checking a train is rarely resorted to, however, except in case of danger. The introduction of the "continuous" or "air" brake, which can be thrown into action in an instant on every car of the train by the engine-driver, is so efficient that it is now almost universally adopted. It is one of the most important safeguards which American ingenuity has yet devised. In drawing a train weighing 150 tons at the rate of 60 miles an hour, about 800 effective horse-power is required. A speed of 80 miles an hour has been often attained, and 100 miles has probably been reached.

The American locomotive-engine has a maximum life which may be stated at about 30 years. The annual cost of repairs is from 10 to 15 per cent. of its first cost. On moderately level roads, the engine requires a pint of oil to each 25 miles, and a ton of coal to each 40 or 50 miles run.

One of the best-managed railroads in the United States reports expenses as follows for one month:

Number "train-miles" run per ton of coal burned	53.95
" " " " quart of oil used	34.44
Passenger-cars hauled 1 mile per ton of coal	275.7
Other " " " " "	634.8
Cost repairs per mile run	$2 43
" fuel " "	3 64
" oil and waste per mile run	62
" wages of engine-men per mile run	6 22
All other expenses per square mile	1 91
Total cost per "train-mile" run	14 82

Although the above sketch and description represent the construction and performance of the standard locomotive of the present time, there are indications that the compound arrangement of engines will ultimately be adopted. This will involve a considerable change of proportions, greatly increasing the volume and weight of steam-cylinders, but enabling the designer to more than proportionally decrease the weight of boiler and the quantity of fuel carried. There is no serious objection to their use, however, and no insuperable difficulty in the construction of the "double-cylinder" type of engine for the locomotive. A few such engines have already been put in service. In these engines the high-pressure cylinder is placed on one side and the larger low-pressure cylinder on the other side of the locomotive, thus having but two cylinders, as in the older plan. The valve-gear is the Stephenson link, as in the ordinary engine. At starting, the steam is allowed to act on both pistons; but after a few revolutions the course of the steam is changed, and the exhaust from the smaller cylinder, instead of passing into the chimney, is sent to the larger cylinder, which is at the same time cut off from the main steam-pipe. When the engine is ascending a steep gradient the steam may, if necessary, be taken from the boiler into both cylinders, as when starting.

Compound engines of this kind have been used on the French line of railroad from Bayonne to Biarritz. They were designed by Mallet and built at Le Creuzot. The steam-cylinders are of $9\frac{1}{2}$ and $15\frac{3}{4}$ inches diameter, and of $17\frac{3}{4}$ inches stroke of piston. The four driving-wheels are 4 feet in diameter, and the total weight of engine is 20 tons. The boiler has $484\frac{1}{2}$ square feet of heating-surface, and is built to carry 10 atmospheres pressure. When hauling trains of 50 tons at 25 miles an hour, these engines require about 15 pounds of good coal per mile.

The total length of the railways in operation in the United States on the 1st day of January, 1877, was 76,640 miles,[1] being an average of one mile of railway for every 600 inhabitants. The railways are as follows:

	Miles.		Miles.		Miles.
Alabama	1,722	Kentucky	1,464	Ohio	4,680
Alaska	0	Louisiana	539	Oregon	251
Arizona	0	Maine	987	Pennsylvania	5,896
Arkansas	787	Maryland	1,092	Rhode Island	182
California	1,854	Massachusetts	1,825	South Carolina	1,352
Colorado	950	Michigan	3,437	Tennessee	1,638
Connecticut	925	Minnesota	2,024	Texas	2,072
Dakota	290	Mississippi	1,028	Utah	486
Delaware	285	Missouri	3,016	Vermont	810
Florida	484	Montana	0	Virginia	1,648
Georgia	2,308	Nebraska	1,181	Washington	110
Idaho	0	Nevada	714	West Virginia	576
Illinois	6,980	New Hampshire	942	Wisconsin	2,575
Indiana	4,072	New Jersey	1,594	Wyoming	459
Indian Territory	281	New Mexico	0		
Iowa	3,937	New York	5,520	Total	76,640
Kansas	3,226	North Carolina	1,371		

In 1873 came the great financial crisis, with its terrible results of interrupted production, poverty, and starvation, and an almost total cessation of the work of building new railroads. The largest number of miles ever built in any one year were constructed in 1872. The greatest mileage is in Illinois, reaching 6,589; the smallest in Rhode Island, 136, and in Washington Territory, 110. The State of Massachusetts has one mile of railroad to 4.86

[1] January, 1892, about 175,000 miles.

miles of territory, this ratio being the greatest in the country. The longest road in operation is the Chicago & Northwestern, extending 1,500 miles; the shortest, the Little Saw-Mill Run Road in Pennsylvania, which is but three miles in length. The total capital of railways in the country is $17,000,000,000, or an average of $30,000 per mile. The earnings for the year 1892 amounted to $900,000,000, or $5,500 per mile. The largest net earnings recorded as made on any road were gained by the New York Central in the year 1872, $8,260,827; the smallest on several roads which not only earned nothing, but incurred a loss.

The catastrophe of 1873–'74 revealed the fact that the latter condition of railroad finances was vastly more common than had been suspected; and it is still doubtful whether the existing immense network of railroads which covers the United States can be made, as a whole, to pay even a moderate return on the money invested in their construction. At the period of maximum rate of extension of railroads in the United States—1873—the reported lengths of the railroads of Europe and America were as follows: [1]

RAILROADS IN EUROPE AND AMERICA IN 1873.

COUNTRIES.	Railroads, Miles.	Population.	Area, Sq. Miles.
United States	71,565	40,232,000	2,492,316
Germany	12,207	40,111,265	212,091
Austria	5,865	35,943,592	227,234
France	10,333	36,469,375	201,900
Russia in Europe	7,044	71,207,794	1,992,574
Great Britain, 1872	15,814	31,817,108	120,769
Belgium	1,301	4,839,094	11,412
Netherlands	886	3,858,055	13,464
Switzerland	820	2,669,095	15,233
Italy	3,667	26,273,776	107,961
Denmark	420	1,784,741	14,453
Spain	3,401	16,301,850	182,758
Portugal	453	3,987,867	36,510
Sweden and Norway	1,049	5,860,122	188,771
Greece	100	1,332,508	19,941

[1] *Railroad Gazette.*

The railroads in Great Britain comprise over 27,000 miles of track now being worked in the United Kingdom, on which have been expended $3,500,000,000. This sum is equal to four times the amount of the annual value of all the real property in Great Britain, and nearly that of the national debt. After deducting all the working expenses, the gross net annual revenue of all the roads exceeds by $110,000,000 the total revenue from all sources of Belgium, Holland, Portugal, Denmark, Sweden, and Norway. In the United States, in 1890, the extent of new track was increasing at the average rate of 5,000 or 6,000 miles annually.

Section III.—Marine Engines.

The changes which have now become completed in the marine steam-engine have been effected at a later date than those which produced the modern locomotive. On the American rivers the modification of the beam-engine since the time of Robert L. Stevens has been very slight. The same general arrangement is retained, and the details are little, if at all, altered. The pressure of steam is sometimes as high as 60 pounds per square inch.

The valves are of the disk or poppet variety, rising and falling vertically. They are four in number, two steam and twonexhaust valves being placed at each end of the steam-cylinder. The beam-engine is a peculiarly American type, seldom if ever seen abroad. Fig. 130 is an outline sketch of this engine asnbuilt for a steamer plying on the Hudson River. This class of engine is usually adopted in vessels of great length, light draught, and high speed. But one steam-cylinder is commonly used. The cross-head is coupled to one end of the beam by means of a pair of links, and the motion of the opposite end of the beam is transmitted to the crank by a connecting-rod of moderate length. The beam has a cast-iron centre surrounded by a wrought-iron strap of lozenge shape, in which are forged the bosses for the end-centres, or for the pins to which the connecting-rod and the links are attached. The main centre of the beam is supported by a "gallows-frame" of timbers so arranged as to receive all stresses longitudinally.

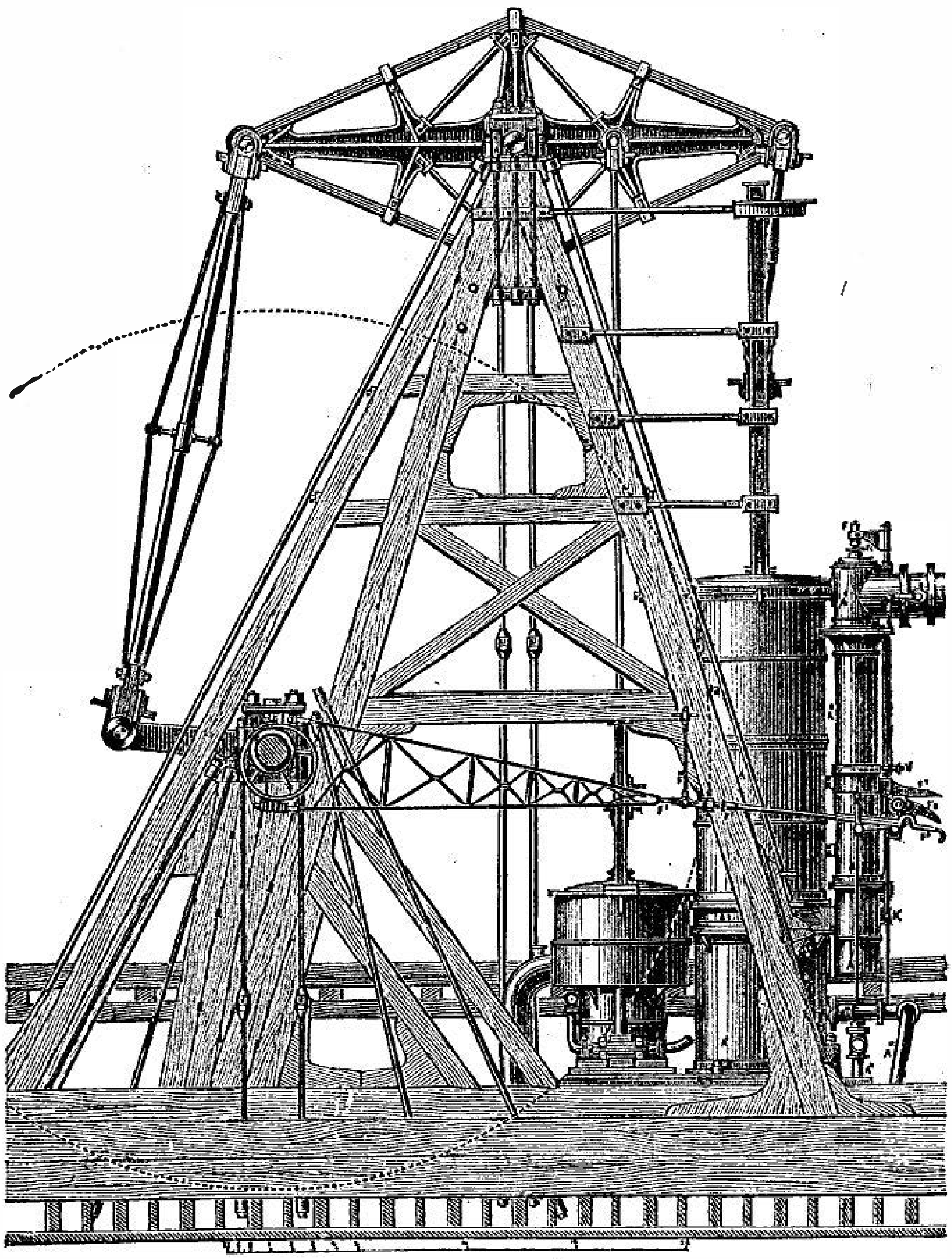


FIG. 130.—Beam-Engine.

The crank and shaft are of wrought-iron. The valve-gear is usually of the form already mentioned as the Stevens valve-gear, the invention of Robert L. and Francis B. Stevens. The condenser is placed immediately beneath the steam-cylinder. The air-pump is placed close beside it, and worked by a rod attached to the beam. Steam-vessels on the Hudson River have been driven by such engines at the rate of 20 miles an hour. This form of engine is remarkable for its smoothness of operation, its economy and durability, its compactness, and the latitude which it permits in the change of shape of the long, flexible vessels in which it is generally used, without injury by "getting out of line."

For paddle-engines of large vessels, the favorite type,

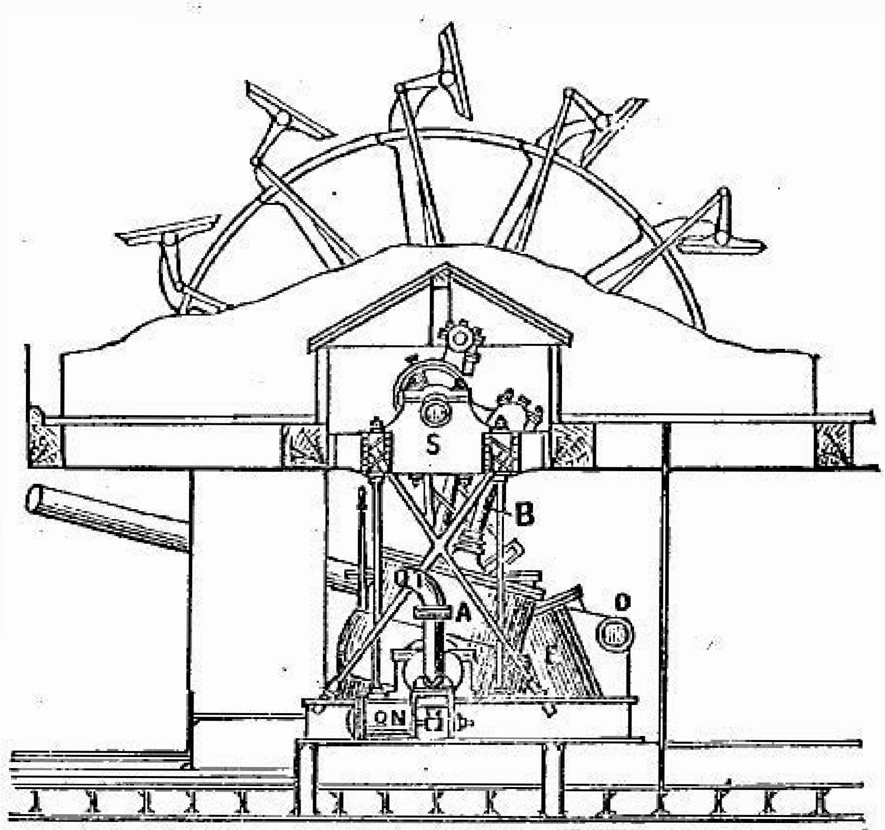


Fig. 131.—Oscillating Engine and Feathering Paddle-Wheel.

which has been the side-lever engine, is now rarely built. For smaller vessels, the oscillating engine with feathering paddle-wheels is still largely employed in Europe. This style of engine is shown in Fig. 131. It is very compact, light, and moderately economical, and excels in simplicity. The usual arrangement is such that the feathering-wheel has the same action upon the water as a radial wheel of double diameter. This reduction of the diameter of the wheel, while retaining maximum effectiveness, permits a high speed of engine, and therefore less weight, volume, and cost. The smaller wheel-boxes, by offering less resistance to the wind, retard the progress of the vessel less than those of radial wheels. Inclined engines are sometimes used for driving paddle-wheels. In these the steam-cylinder lies in an inclined position, and its connecting-rod directly connects the crank with the cross-head. The condenser and air-pump usually lie beneath the cross-head guides, and are worked by a bell-crank driven by links on each side the connecting-rod, attached to the cross-head. Such engines are used to some extent in Europe, and they have been adopted in the United States navy for side-wheel gunboats. They are also used on the ferry-boats plying between New York and Brooklyn.

Among the finest illustrations of recent practice in the construction of side-wheel steamers are those built for the several routes between New York and the cities of New England which traverse Long Island Sound. Our illustration exhibits the form of these vessels, and also shows well the modifications in structure and size which have been made during this generation. The later vessel is 325 feet long, 45 feet beam, 80 feet wide over the "guards," and 16 feet deep, drawing 10 feet of water. The "frames" upon which the planking of the hull is fastened are of white-oak, and the lighter and "top" timbers of cedar and locust. The engine has a steam-cylinder 90 inches in diameter and 12 feet stroke of piston.[1] On each side the great saloons which extend from end to end of the upper deck are state-rooms, containing each two berths and elegantly furnished. The engine of this vessel is capable of developing about 2,500 horse-power. The great wheels, of which the paddle-boxes are seen rising nearly to the height of the hurricane-deck, are 37½ feet in diameter and 12 in breadth. The hull of this vessel, including all wood-work, weighs over 1,200 tons. The weight of the machinery is about 625 tons. The steamer makes 16 knots an hour when the engine is at its best speed—about 17 revolutions per minute—and its

[1] The steam-cylinders of the engines of steamers Bristol and Providence are 110 inches in diameter and of 12 feet stroke.

average speed is about 14 knots on its route of 160 miles. The coal required to supply the furnaces of such a vessel and with such machinery would be about 3 tons per hour,

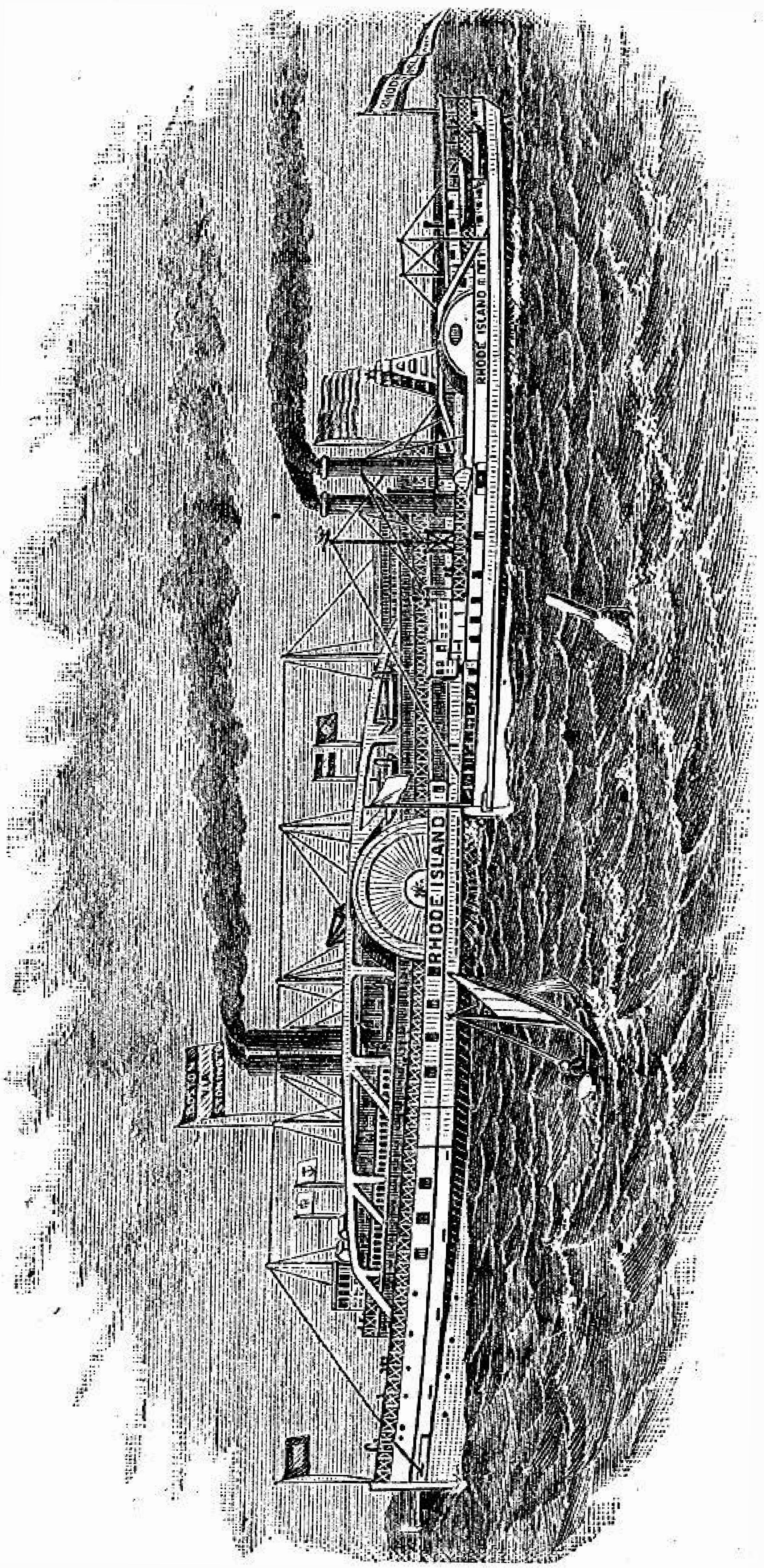


FIG. 132.—The Two Rhode Islands, 1836–1876.

or a little over $2\frac{1}{2}$ pounds per horse-power. The construction of such a vessel occupies, usually, about a year, and costs a quarter of a million dollars.

The non-condensing direct-acting engine is used principally on the Western rivers, driven by steam of from 100 to 150 pounds pressure, and exhausts its steam into the atmosphere. It is the simplest possible form of direct-acting engine. The valves are usually of the "poppet" variety, and are operated by cams which act at the ends of long

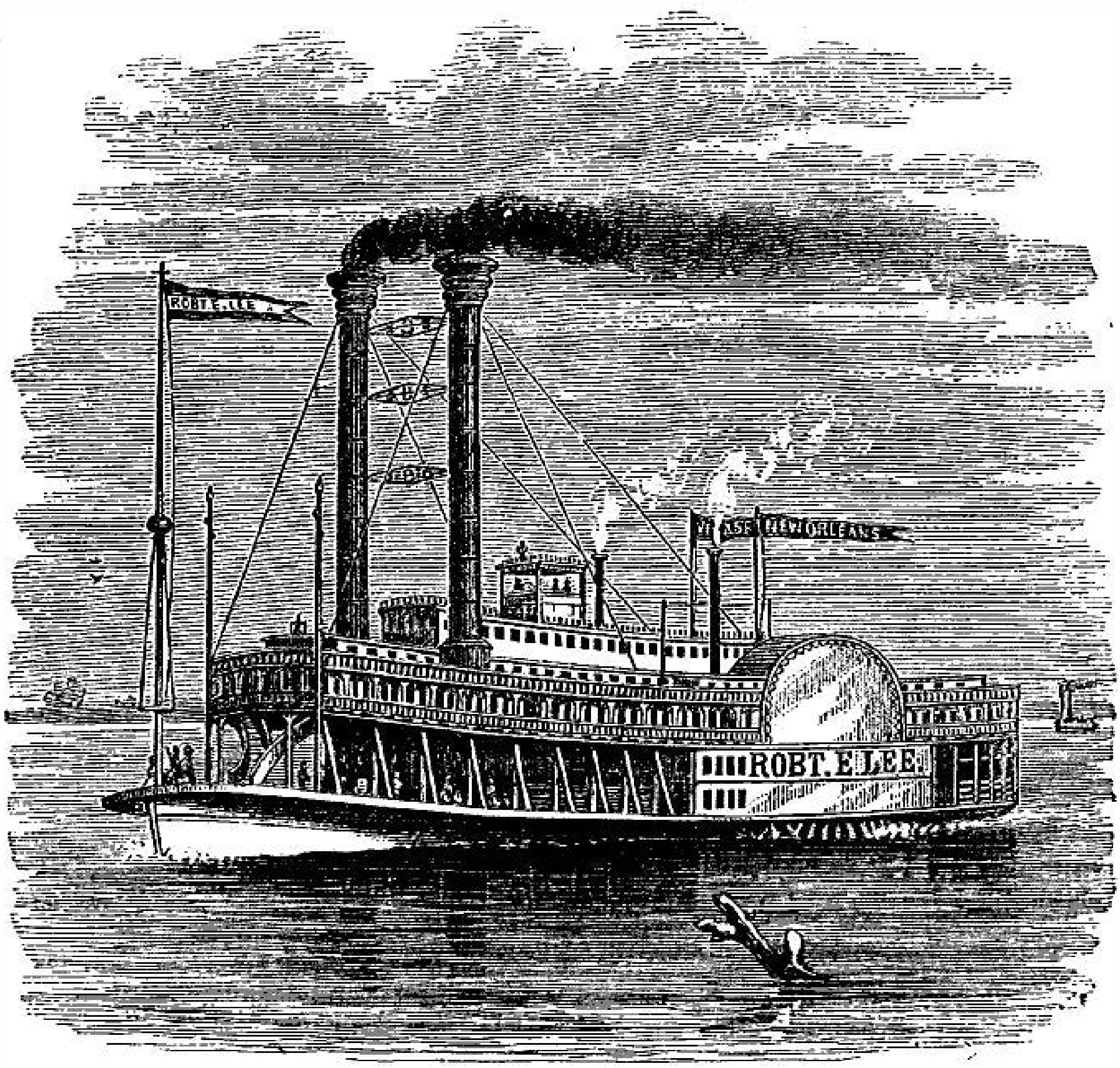


FIG. 133.—A Mississippi Steamboat.

levers having their fulcra on the opposite side of the valve, the stem of which latter is attached at an intermediate point. The engine is horizontal, and the connecting-rod directly attached to cross-head and crank-pin without intermediate mechanism. The paddle-wheel is used, sometimes as a stern-wheel, as in the plan of Jonathan Hulls of one and a half century ago, sometimes as a side-wheel, as is most usual elsewhere. One of the most noted of these steamers, plying on the Mississippi, is shown in the preceding sketch.

One of the largest of these steamers was the Grand Republic,[1] a vessel 340 feet long, 56 feet beam, and 10¼ feet depth. The draught of water of this great craft was 3½ feet forward and 4½ aft. The two sets of compound engines, 28 and 56 inches diameter and of 10 feet stroke, drive wheels 38½ feet in diameter and 18 feet wide. The boilers were steel. A steamer built still later on the Ohio bas the following dimensions: Length, 225 feet; breadth, 35½ feet; depth, 5 feet; cylinders, 17⅝ inches in diameter, 6 feet stroke; three boilers. The hull and cabin were built at Jeffersonville, Ind. She has 40 large state-rooms. The cost of the steamer was $40,000.

These vessels have now opened to commerce the whole extent of the great Mississippi basin, transporting a large share of the products of a section of country measuring a million and a half square miles—an area equal to many times that of New York State, and twelve times that of the island of Great Britain—an area exceeding that of the whole of Europe, exclusive of Russia and Turkey, and capable, if as thoroughly cultivated as the Netherlands, of supporting a population of between three and four hundred millions of people.

The steam-engine and propelling apparatus of the modern ocean-steamer have now become almost exclusively the compound or double-cylinder engine, driving the screw. The form and the location of the machinery in the vessel vary with the size and character of the ship which it drives. Very small boats are fitted with machinery of quite a different kind from that built for large steamers, and war-vessels have usually been supplied with engines of a design radically different from that adopted for merchant-steamers.

The introduction of *Steam-Launches* and small pleasure-

[1] Burned in 1877.

boats driven by steam-power is of comparatively recent date, but their use is rapidly increasing. Those first built were heavy, slow, and complicated ;nbut, profiting by ex-

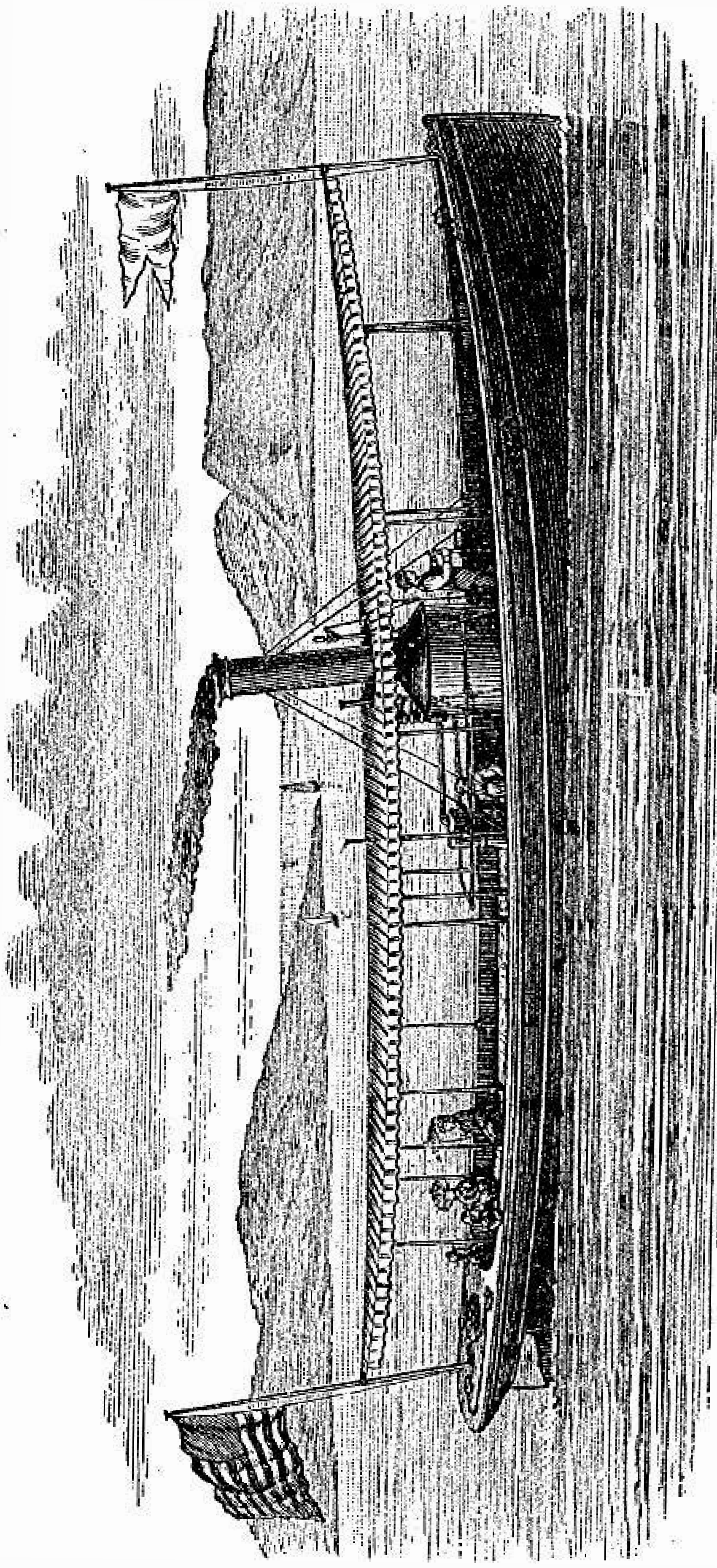


FIG. 134.—Steam-Launch, New York Steam-Power Company.

perience, light and graceful boats are now built, of remarkable swiftness, and having such improved and simplified machinery that they require little fuel and can be easily managed. Such boats have strong, carefully-modeled hulls, light and strong boilers, capable of making a large amount of dry steam with little fuel, and a light, quick-running en-

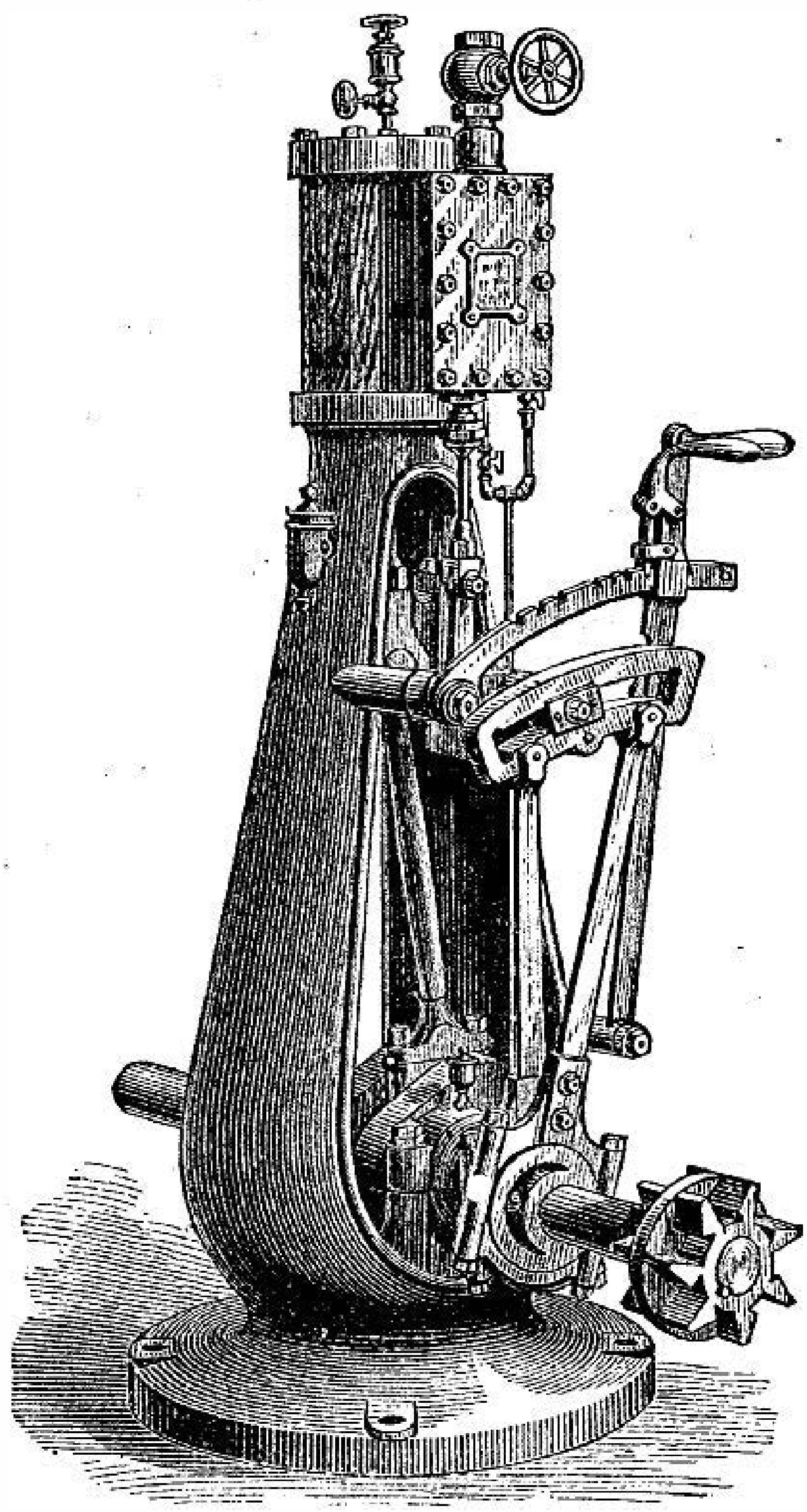


FIG. 135.—Launch-Engine.

gine, working without shake or jar, and using steam economically.

The above sketch represents the engine built by a New York firm for such little craft. This is the smallest size made for the market. It has a steam-cylinder 3 inches in diameter and a stroke of piston of 5 inches, driving a screw 26 inches in diameter and of 3 feet pitch. The maximum power of the engine is four or five times the nominal power. The boiler is of the form shown in the illustrations of semi-portable engines, and has a heating-surface, in this case, of 75 square feet. The boat itself is like that seen on page 386, and is 25 feet long, of 5 feet 8 inches beam, and draws $2\frac{1}{4}$ feet of water. These little machines weigh about 150 pounds per nominal horse-power, and the boilers about 300.

Some of these little vessels have attained wonderful speed. A British steam-yacht, the Miranda, $45\frac{1}{2}$ feet in length, $5\frac{3}{4}$ feet wide, and drawing $2\frac{1}{2}$ feet of water, with a total weight of $3\frac{3}{4}$ tons, has steamed nearly $18\frac{1}{2}$ miles an hour for short runs. The boat was driven by an engine of 6 inches diameter of cylinder and 8 inches stroke of piston, making 600 revolutions per minute, driving a two-bladed screw $2\frac{1}{2}$ feet in diameter and of $3\frac{1}{3}$ feet pitch. Its machinery had a total weight of two tons. Another English yacht, the Firefly, is said to have made 18.94 miles an hour. A little French yacht, the Hirondelle, has attained a speed of 16 knots, equal to about $18\frac{1}{2}$ miles, an hour. This was, however, a much larger vessel than the preceding. One of the most remarkable of these little steamers is a torpedo-boat built for the United States navy. This vessel is 60 feet long, 6 feet wide, and 5 feet deep; its screw is 38 inches in diameter and of 5 feet pitch, two-bladed, and is driven, by a very light engine and boiler, 400 revolutions per minute, the boat attaining a speed of 19 to 20 miles an hour. These craft are now built fromal00 to 200 feet long and, developing over 3,000 horse-power, attain speeds exceeding 30 knots—35 miles an hour.

Yachts of high speed require such weight and bulk of engine that but little space is left for cabins, and they are usually exceedingly uncomfortable vessels.a In the Miranda the weight of machinery is more than one-half the total weight of the whole. An illustration of theamore comfortable and more generally liked pleasure-yacht is the Day Dream. The length is 105 feet, and the boat draws $5\frac{1}{2}$

feet of water. There are two engines, having steam-cylinders 14 inches in diameter and of the same length of stroke, direct-acting, condensing, and driving a screw, of 7 feet diameter and of 10½ feet pitch, 135 revolutions a minute, giving the yacht a speed of 13½ knots an hour.

In larger vessels, as in yachts, in nearly all cases, the ordinary screw-engine is direct-acting. Two engines are placed side by side, with cranks on the shaft at an angle of 90ñ with each other. In merchant-steamers the steam-cylinders are usually vertical and directly over the crank-pins, to which the cross-heads are coupled. The condenser is placed behind the engine-frame, or, where a jet-condenser is used, the frame itself is sometimes made hollow, and serves as a condenser. The air-pump is worked by a beam connected by links with the cross-head. The general arrangement is like that shown in Figs. 137 and 138. For naval purposes such a form is objectionable, since its height is so great that it would be exposed to injury by

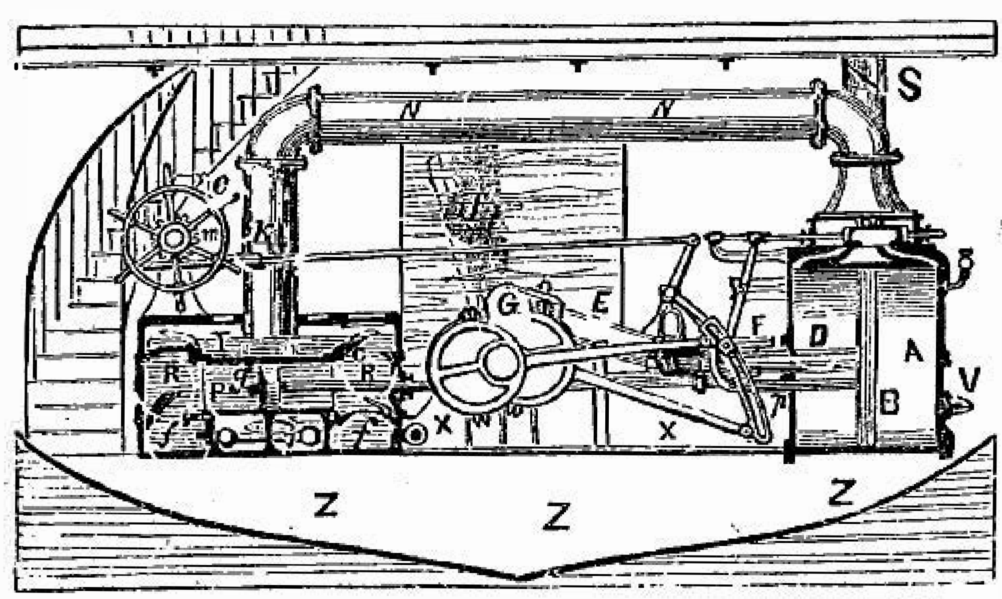


FIG. 136.—Horizontal, Direct-acting Naval Screw-Engine.

shot. In naval engineering the cylinder is placed horizontally, as in Fig. 136, which is a sectional view, representing an horizontal, direct-acting naval screw-engine, with jet-condenser and double-acting air and circulating pumps. *A* is the steam-cylinder, *B* the piston, which is connected to the crank-pin by the piston-rod, *D*, and connecting-rod, *E*.

F is the cross-head guide. The eccentrics, *G*, operate the valve, which is of the "three-ported variety," by a Stephenson link. Reversing is effected by the hand-wheel, *C*, which, by means of a gear, *m*, and a rack, *k*, elevates and depresses the link, and thus reverses the valve.

The trunk-engine, in which the connecting-rod is at-

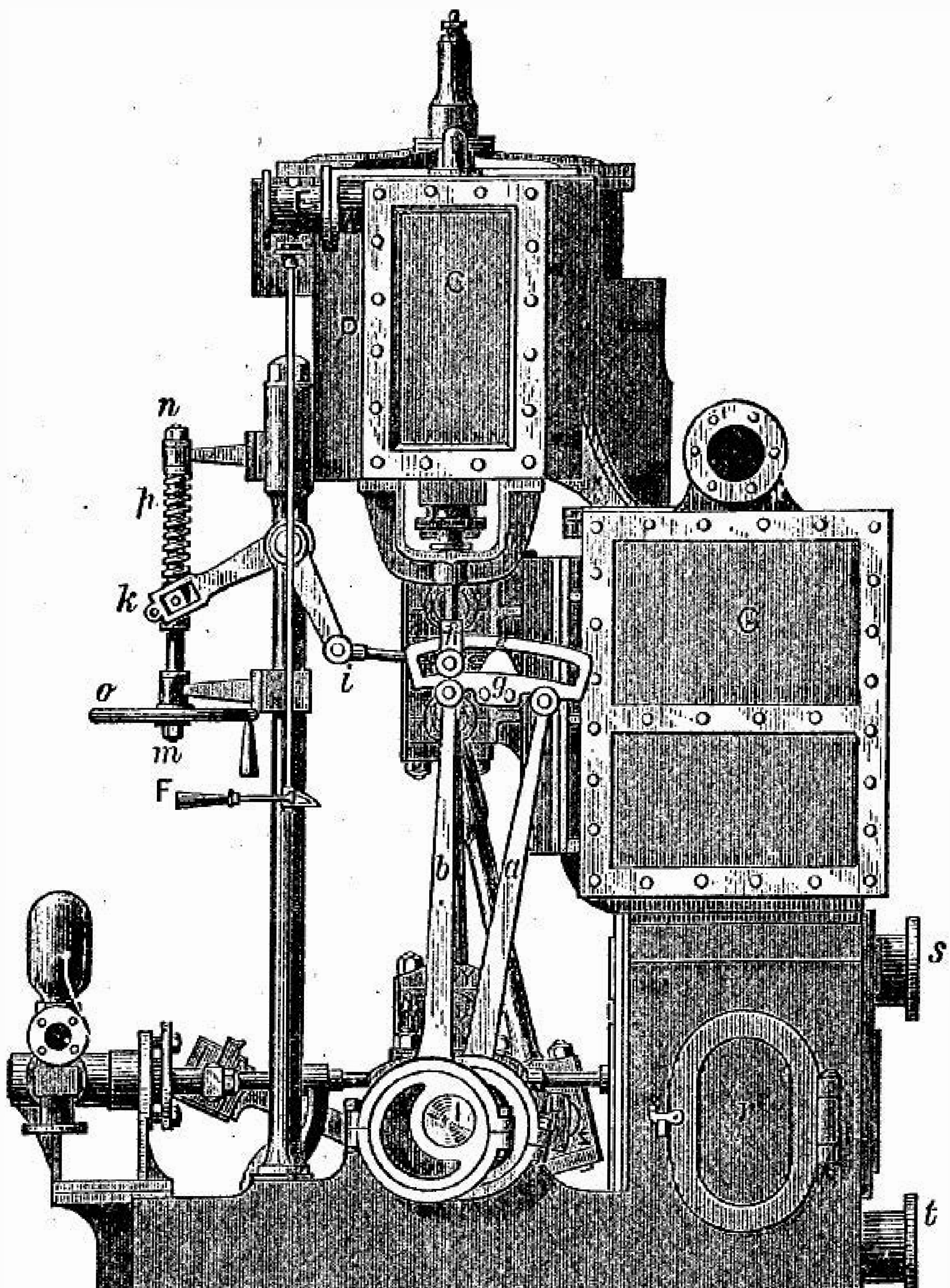


FIG. 137.—Compound Marine Engine. Side Elevation.

tached directly to the piston and vibrates within a trunk or cylinder secured to the piston, moving with it, and extending outside the cylinder, like an immense hollow piston-rod, is frequently used in the British navy. It has rarely been adopted in the United States.

In nearly all steam-vessels which have been built for the merchant service recently, and in some naval vessels, the compound engine has been adopted. Figs. 137 and 138 represent the usual form of this engine. Here *A A*, *B B* are the small and the large, or the high-pressure and the low-pressure cylinders respectively. *C C* are the valve-

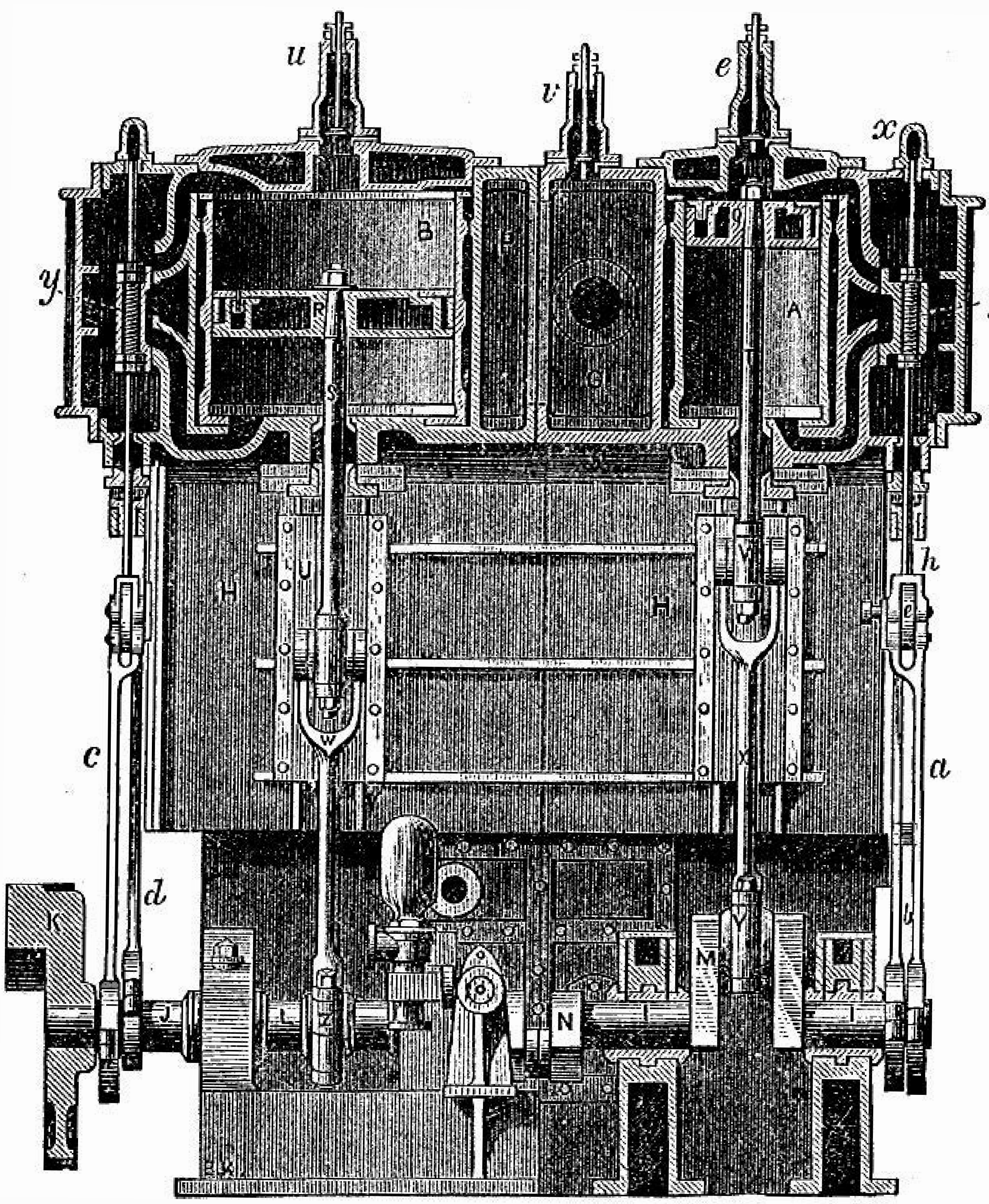


FIG. 138.—Compound Marine Engine. Front Elevation and Section.

chests. *G G* is the condenser, which is invariably a surface-condenser. The condensing water is sometimes directed around the tubes contained within the casing, *G G*, while the steam is exhausted around them and among them, and sometimes the steam is condensed within the tubes, while the injection-water which is sent into the condenser to produce condensation passes around the exterior of the tubes. In either case, the tubes are usually of small diameter, varying from five-eighths to half an inch, and in length from four to seven feet. The extent of heating-surface is usually from one-half to three-fourths that of the heating-surface of the boilers.

The air and circulating pumps are placed on the lower part of the condenser-casting, and are operated by a crank on the main shaft at *N*; or they are sometimes placed as in the style of engine last described, and driven by a beam worked by the cross-head. The piston-rods, *T S*, are guided by the cross-heads, *V V*, working in slipper-guides, and to these cross-heads are attached the connecting-rods, *X X*, driving the cranks, *M M*. The cranks are now usually set at right angles; in some engines this angle is increased ton 120°, or even 180°. Where it is arranged as here shown, an intermediate reservoir, *P* ●, is placed between the two cylinders to prevent the excessive variations of pressure that would otherwise accompany the varying relative motions of the pistons, as the steam passes from the high-pressure to the low-pressure cylinder. Steam from the boilers enters thenhigh-pressure steam-chest, *X*, and is admitted by the steam-valve alternately above and below the piston as usual. The exhaust steam is conducted through the exhaust passage around into the reservoir, *P*, whence it it is taken by the low-pressure cylinder, precisely as the smaller cylinder drew its steam from the boiler. From the large or low-pressure cylinder the steam is exhausted into the condenser. The valve-gear is usually a Stephenson link, *g e*, the position of which is determined, and the reversal of which is accomplished, by a hand-wheel, *o*, and screw, *m n p*, which, by the bell-crank, *k i*, are attached to the link, *g e*. The "box-framing" forms also the hot-well. The surface-condenser is cleared by a single-acting air-pump, inside the frame, at *T.* The feed-pump and the bilge-pumps are driven from the cross-head of the air-pump.

The successful introduction of the double-cylinder engine was finally accomplished by the exertions of a few engineers, who were at once intelligent enough to understand its advantages, and energetic and enterprising enough to push it forward in spite of active opposition, and powerful enough, pecuniarily and in influence, to succeed.

John Elder.

The most active and earnest of these eminent men was John Elder, of the firm of Randolph, Elder & Co., subsequently John Elder & Co., of Glasgow.[1]

Elder was of Scotch descent. His ancestors had, for

[1] *Vide* "Memoir of John Elder," W. J. M. Rankine, Glasgow, 1871.

generations, shown great skill and talent in construction, and had always been known as successful millwrights. John Elder was born at Glasgow, March 8, 1824, and died in London, September 17, 1869. He was educated at the Glasgow High-School and in the College of Engineering at the University of Glasgow, where, however, his attendance was but for a short time. He learned the trade under his father in the workshops of the Messrs. Napier, and became an unusually expert draughtsman. After spending three years in charge of the drawing-office at the engine-building works of Robert Napier, where his father had been manager, Elder became a partner in the firm which had previously been known as Randolph, Elliott & Co., in the year 1852. The firm commenced building iron vessels in 1860.

In the mean time, the experiments of Hornblower and Wolff, of Allaire and Smith, and of McNaught, Craddock, and Nicholson, together with the theoretical investigations of Thompson, Rankine, Clausius, and others, had shown plainly in what direction to look for improvement upon then standard engines, and what direction practice was taking with all types. The practical deductions which were becoming evident were recognized very early by Elder, and he promptly began to put in practice the principles which his knowledge of thermo-dynamics and of mechanics enabled him to appreciate. He adopted the compound engine, and coupled his cranks at angles of 180°, in order to avoid losses due to the friction of the crank-shaft in its bearings, by effecting a partial counterbalancing of pressures on the journals. Elder was one of the first to point out the fact that the compound engine had proved itself more efficient than the single-cylinder engine, only when the pressure of steam carried and the extent to which expansion was adopted exceeded the customary practice of his time. His own practice was, from the first, successful, and from 1853 to 1867 he and his partners were continually engaged in the construction of steamers and fitting them with compound engines.

The engines of their first vessel, the Brandon, required but $3\frac{1}{4}$ pounds of coal per hour and per horse-power, in 1854, when the usual consumption was a third more. Five years later, they had built engines which consumed a third less than those of the Brandon; and thenceforward, for many years, their engines, when of large size, exhibited what was then thought remarkable economy, running on a consumption of from $2\frac{1}{4}$ to $2\frac{1}{2}$ pounds.

In the year 1865 the British Government ordered a competitive trial of three naval vessels, which only differed in the form of their engines. The Arethusa was fitted with trunk-engines of the ordinary kind; the Octavia had three steam-cylinders, coupled to three cranks placed at angles of 120° with each other; and the Constance was fitted with compound engines,—two sets of three cylinders each, and each taking steam from the boiler into one cylinder, passing it through the other two with continuous expansion, and finally exhausting from the third into the condenser. These vessels, during one week's steaming at sea, averaged, respectively, 3.64, 3.17, and 2.51 pounds of coal per hour and per horse-power, and the Constance showed a marked superiority in the efficiency of the mechanism of her engines, when the losses by friction were compared.

The change from the side-lever single-cylinder engine, with jet-condenser and paddle-wheels, to the direct-acting compound engine, with surface-condenser and screw-propellers, has occurred within the memory and under the observation of even young engineers, and it may be considered that the revolution has not been completely effected. This change in the design of engine is not as great as it at first seemed likely to become. Builders have but slowly learned the principles stated above in reference to expansion in one or more cylinders, and the earlier engines were made with a high and low pressure cylinder working on the same connecting-rod, and each machine consisted of four steam-cylinders. It was at last discovered that a high-pressure single-cylinder engine exhausting into a separate larger low-pressure engine might give good results, and the compound engine became as simple as the type of engine which it displaced. This independence of high and low pressure engines is not in itself novel, for the plan of using the exhaust of a high-pressure engine to drive a low-pressure condensingn engine was one of the earliest of known combinations.

The advantage of introducing double engines at sea is considerably greater than on land. The coal carried by a steam-vessel is not only an item of great importance in consequence of its first cost, but, displacing its weight or bulk of freight which might otherwise be carried, it represents so much non-paying cargo, and is to be charged with the fulln cost of transportation in addition to first cost. The best of steam-coal is therefore usually chosen for steamers making long voyages, and the necessity of obtaining the most economical engines is at once seen, and is fully appreciated by steamship proprietors. Again, an economy of one-fourth of a pound per horse-power per hour gives, on a large transatlantic steamer, a saving of about 100 tons of coal for a single voyage. To this saving of cost is to be added the gain in wages and sustenance of the labor required to handle that coal, and the gain by 100 tons of freight carried in place of the coal.

For many years the change which has here been outlined, in the forms of engine and the working of steam expansively, was retarded by the inefficiency of methods and tools used in construction. With gradual improvement in tools and in methods of doing work, it became possible to control higher steam and to work it successfully; and the change in this direction has been steadily going on up to the present time with all types of steam-engine. At sea this rise of pressure was for a considerable time retarded by the serious difficulty encountered in the tendency of the sulphate of lime to deposit in the boiler. When steam-pressure had risen to 25 pounds per square inch, it was found that no amount of "blowing out" would prevent the deposition of seriously large quantities of this salt, while atn the lower pressures at first carried atnsea no troublesome precipitation occurred, and the only precaution necessary was to blow out sufficient brine to prevent the precipitation of common salt from a supersaturated solution. The introduction of surface-condensation was promptly attempted as the remedy for this evil, but for many years it was extremely doubtful whether its disadvantages were not greater than its advantages. It was found very difficult to keep the condensers tight, and boilers were injured by some singular process of corrosion, evidently due to the presence of the surface-condenser. The simple expedient of permitting a very thin scale to form in the boiler was, after a time, hit upon as a means of overcoming this difficulty, and thenceforward the greatest obstacle to the general introduction was the conservative disposition found among those who had charge of marine machinery, which conservatism regarded with suspicion every innovation. Another trouble arose from the difficulty of finding men neither too indolent nor too ignorant to take charge of the new condenser, which, more complicated and more readily disarranged than the old, demanded a higher class of attendants. Once introduced, however, the surface-condenser removed the obstacle to further elevation of steam-pressure, and the rise from 20 to 60 pounds pressure soon occurred. Eldernand his competitors on the Clyde were the first to take advantage of the fact when these higher pressures became practicable.

The lightness of engine and the smaller weight of boiler secured when the simpler type of "compound" engine is used are great advantages, and, when coupled with the fact that by no other satisfactory device can great expansion and consequent economy of fuel be obtained at sea, the advantages are such as to make the adoption of this style of engine imperative for ship-propulsion.

This extreme lightness in machinery has been largely, also, the result of very careful and skillful designing, of intelligent construction, and of care in the selection and use of material. British builders had, until after the introduction of these later types of vessels-of-war, been distinguished rather by the weight of their machinery than for nice calculation and proportioning of parts. Now the engines of the heavy iron-clads are models of good proportions, excellence in materials, and of workmanship, which are well worthy of study. The weight per indicated horse-power has been reduced from 200 or 300 pounds to less than half that amount within the last ten years. This has been accomplished by forcing the boilers—although thus, to some extent, losing economy—by higher steam-pressure, a very much higher piston-speed, reduction of friction of parts, reduction of capacity for coal-stowage, and exceedingly careful proportioning. The reduction of coal-bunker capacity is largely compensated by the increase of economy secured by superheating, by increased expansion, elevation of piston-speed, and the introduction of surface-condensation.

A good marine steam-engine of the form which was considered standard 15 or 20 years ago, having low-pressure boilers carrying steam at 20 or 25 pounds pressure as a maximum, expanding twice or three times, and having a jet-condenser, would require about 30 or 35 pounds of feed-water per horse-power per hour; substituting surface-condensation for that produced by the jet brought down the weight of steam used to from 25 to 30 pounds; increasing steam-pressure to 60 pounds, expanding from five to eight times, and combining the special advantages of the superheater and the compound engine with surface-condensation, has reduced the consumption of steam to 20, or even, in some cases, 15 pounds of steam per horse-power per hour. Messrs. Perkins, of London, guarantee, as has already been stated, to furnish engines capable of giving a horse-power with a consumption of but $1\frac{1}{4}$ pound of coal. Mr.

C. E. Emery reports the United States revenue-steamer Hassler, designed by him, to have given an ordinary sea-going performance which is probably fully equal to anything yet accomplished. The Hassler is a small steamer, of but 151 feet in length, 24½ feet beam, and 10 feet draught. The engines have steam-cylinders 18.1 and 28 inches diameter, respectively, and of 28 inches stroke of piston, indicating 125 horse-power; with steam at 75 pounds pressure, and at a speed of but 7 knots, the coal consumed was but 1.87 pound per horse-power per hour.

The committee of the British Admiralty on designs of ships-of-war have reported recently: "The carrying-power of ships may certainly be to some extent increased by the adoption of compound engines in her Majesty's service. Its use has recently become very general in the mercantile marine, and the weight of evidence in favor of the large economy of fuel thereby gained is, to our minds, overwhelming and conclusive. We therefore beg earnestly to recommend that the use of compound engines may be generally adopted in ships-of-war hereafter to be constructed, and applied, whenever it can be done with due regard to economy and to the convenience of the service, to those already built."

The forms of screws now employed are exceedingly diverse, but those in common use are not numerous. In naval vessels it is common to apply screws of two blades, that they may be hoisted above water into a "well" when the vessel is under sail, or set with the two blades directly behind the stern-post, when their resistance to the forward motion of the vessel will be comparatively small. In other vessels, and in the greater number of full-power naval vessels, screws of three or four blades are used.

The usual form of screw (Fig. 139) has blades of nearly equal breadth from the hub to the periphery, or slightly widening toward their extremities, as is seen in an exaggerated degree in Fig. 140, representing the form adopted for tug-boats, where large surface near the extremity is more generally used than in vessels of high speed running free. In the Griffith screw, which has been much used, the hub

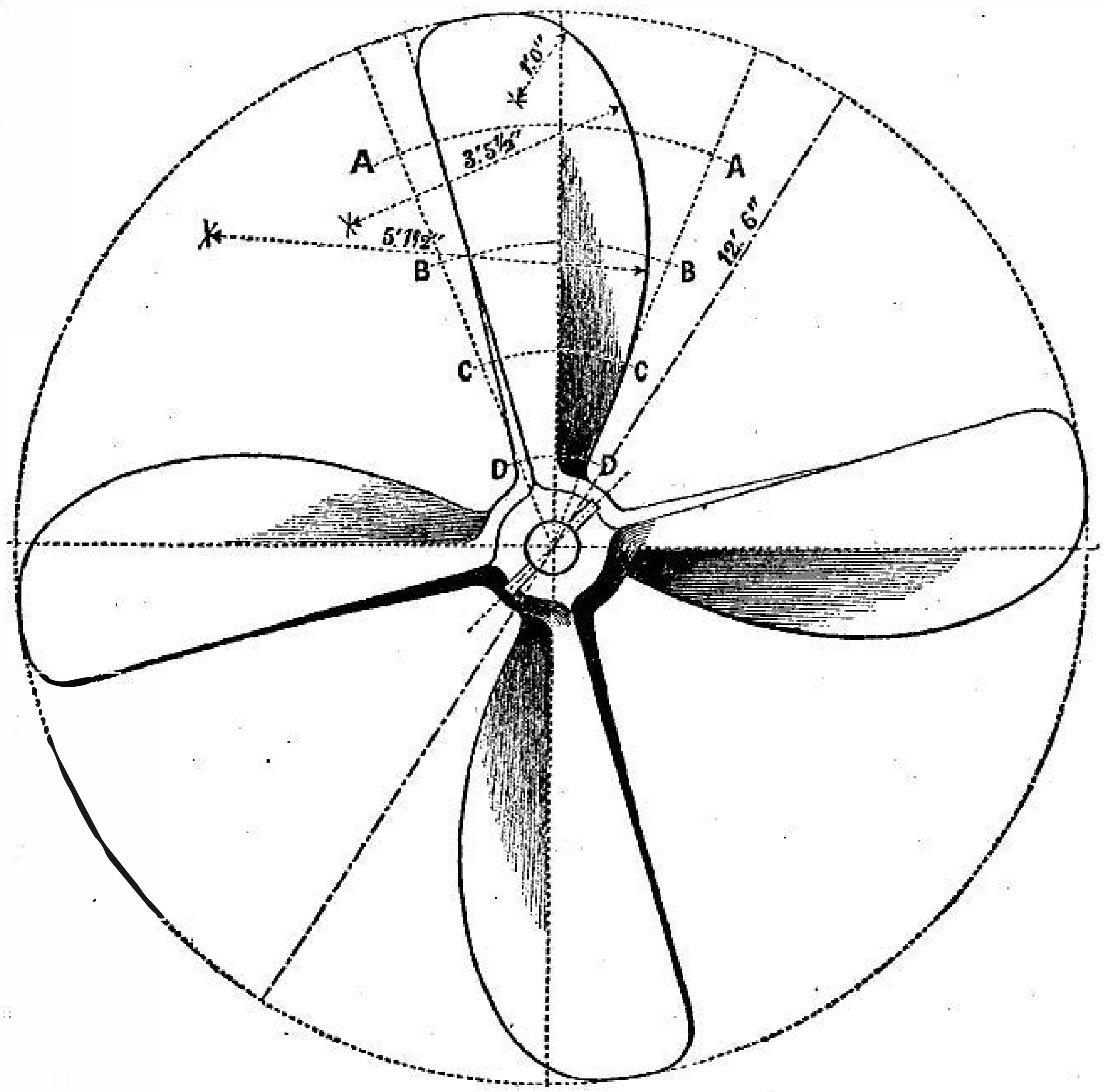


FIG. 139.—Screw-Propeller.

is globular and very large. The blades are secured to the hub by flanges, and are bolted on in such a manner that their position may be changed slightly if desired. The blades are shaped like the section of a pear, the wider part being nearest the hub, and the blades tapering rapidly toward their extremities. A usual form is intermediate between the last, and is like that shown in Fig. 141, the hub being sufficiently enlarged to permit the blades to be attached as in the Griffith screw, but more nearly cylindrical, and the blades having nearly uniform width from end to end.

The pitch of a screw is the distance which would be traversed by the screw in one revolution were it to move through the water without slip; i. e., it is doublerthe distance CD, Fig. 140. CD' represents the helical path of the extremity of the blade B, and $OEFHK$ is that of the blade A. The proportion of diameter to the pitch of the screw is determined by the speed of the vessel. For low speed the pitch may be as small as $1\frac{1}{4}$ the diameter. For vessels of high speed the pitch is frequently double the

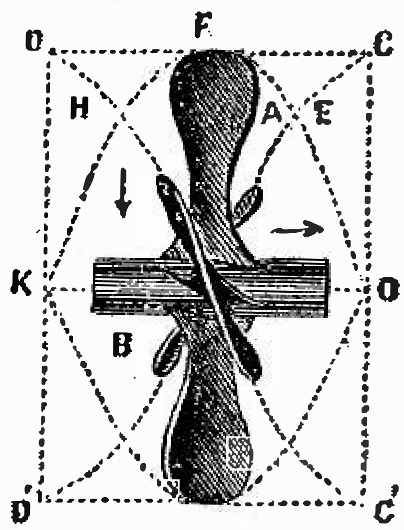


FIG. 140.—Tug-boat Screw.

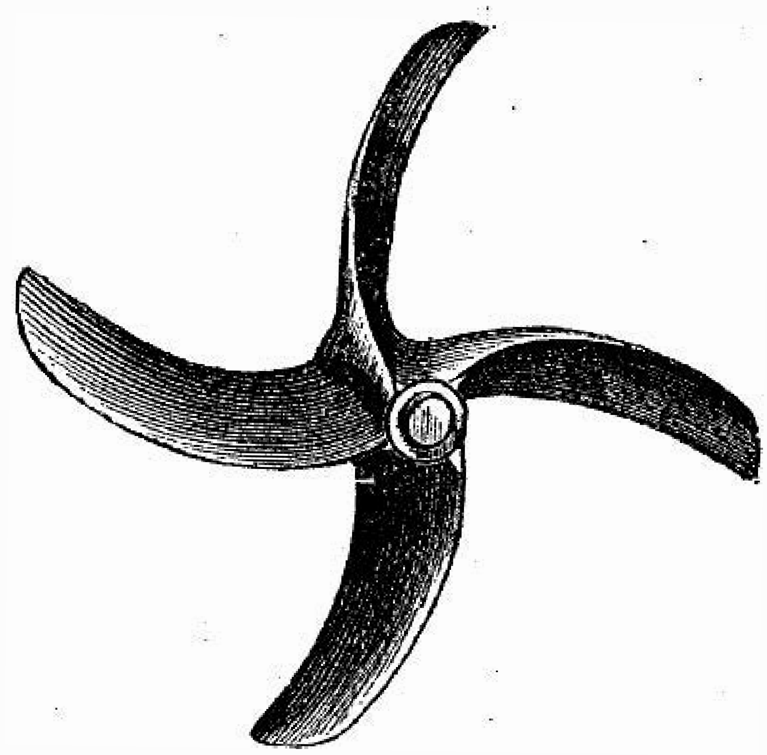


FIG. 141.—Hirsch Screw.

diameter. The diameter of the screw is made as great as possible, since the slip decreases with the increase of the area of screw-disk. Its length is usually about one-sixth of the diameter. A greater length produces loss by increase of surface causing too great friction, while a shorter screw does not fully utilize the resisting power of the cylinder of water within which it works, and increased slip causes waste of power. An empirical value for the probable slip in vessels of good shape, which is closely approximate usually, is $S = 4\frac{M}{A}$, in which S is the slip per cent., and M and A are the areas of the midship section and of the screw-disk in square feet.

The most effective screws have slightly greater pitch at the periphery than at the hub, and an increasing pitch from the forward to the rear part of the screw. The latter method of increasing pitch is more generally adopted alone. The thrust of the screw is the pressure which it exerts in driving the vessel forward. In well-formed vessels, with good screws, about two-thirds of the power applied to the screw is utilized in propulsion, the remainder being wasted in slip and other useless work. Its efficiency is in such a case, therefore, 66 per cent. Twin screws, one on each side of the stern-post, are sometimes used in vessels of light draught and considerable breadth, whereby decreased slip is secured.

As has already been stated, the introduction of the compound engine has been attempted, but with less success than in Europe, by several American engineers.

The most radical change in the methods of ship-propulsion which has been successfully introduced in some localities has been the adoption of a system of "wire-rope towage." It is only well adapted for cases in which the steamer traverses the same line constantly, moving backward and forward between certain points, and is never compelled to deviate to any considerable extent from the path selected. A similar system is in use in Canada, but it has not yet come into use in the United States, notwithstanding the fact that, wherever its adoption is practicable, it has a marked superiority in economy over the usual methods of propulsion. With chain or rope traction there is no loss by slip or oblique action, as in both screw and paddle-wheel propulsion. In the latter methods these losses amount to an important fraction of the total power; they rarely, if ever, fall below a total of 25 per cent., and probably in towage exceed 50 per cent. The objection to the adoption of chain-propulsion, as it is also often called, is the necessity of following closely the line along which the chain or the rope is laid. There is, however, much less difficulty than would be anticipated in following a sinuous route or in avoiding obstacles in the channel or passing other vessels. The system is particularly well adapted for use on canals.

The steam-boilers in use in the later and best marine engineering practice are of various forms, but the standard types are few in number. That used on river-steamers in the United States has already been described.

Fig. 142 is a type of marine tubular boiler which is in most extensive usenin sea-going steamers for moderate pressure, and particularly for naval vessels. Here the gases

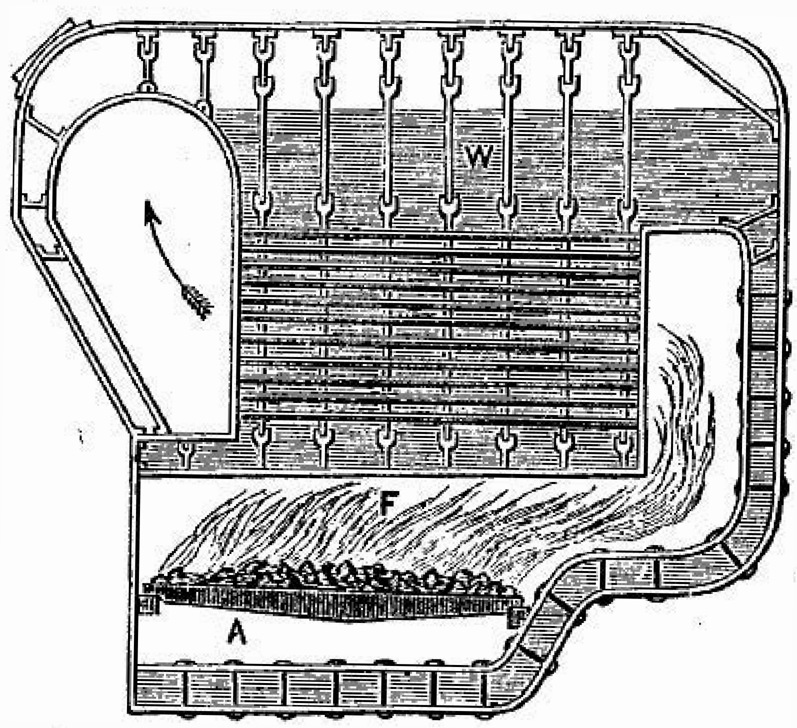


FIG. 142.—Marine Fire-tubular Boiler. Section.

pass directly into the back connection from the fire, and thence forward again, through horizontal tubes, to the front connection and up the chimney. In naval vessels the steam-chimney is omitted, as it is there necessary to keep all parts of the boiler as far below the water-line as possible. Steam is taken from the boiler by pipes which are carried from end to end of the steam-space, near the top of the boiler, the steam entering these pipes through small holesndrilled on the other side. Steam is thus taken from the boiler "wet," but no large quantity of water can usually be "entrained" by the steam.

A marine boiler has been quite extensively introduced into the United States navy, in which the gases are led from the back connection through a tube-box around and among a set of upright water-tubes, which are filled with water, circulation taking place freely from the water-space immediately above the crown-sheet of the furnace up through these tubes into the water-space above them. These "water-tubular" boilers have a slight advantage over the "fire-tubular" boilers already described in compactness, in steaming capacity, and in economical efficiency. They have a very marked advantage in the facility with which the tubes may be scraped or freed from the deposit when a scale of sulphate of lime or other salt has formed within them by precipitation from the water. The fire-tubular boiler excels in convenience of access for plugging up leaking tubes, and is much less costly than the water-tubular. The water-tube class of boilers still remain in extensive use in the United States naval steamers. They have never been much used in the merchant service, although introduced by James Montgomery in the United States and by Lord Dundonald in Great Britain twenty years earlier. Opinion still remains divided among engineers in regard to their relative value. They are gradually

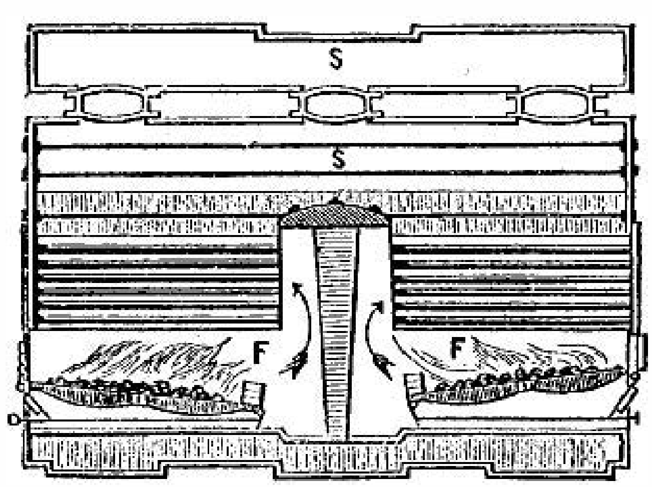


FIG. 143.—Marine High-Pressure Boiler. Section.

reassuming prominence by their introduction in the modified form of sectional boilers.

Marine boilers are now usually given the form shown in section in Fig. 143. This form of boiler is adopted where steam-pressures of 60 pounds and upward are carried, as in steam-vessels supplied with compound engines, cylindrical forms being considered the best with high pressures. The large cylindrical flues, therefore, form the furnaces as shown in the transverse sectional view. The gases rise, as shown in the longitudinal section, through the connection, and pass back to the end of the boiler through the tubes, and thence, instead of entering a steam-chimney, they are conducted by a smoke-connection, not shown in the sketch, to the smoke funnel or stack. In merchant-steamers, a steam-drum is often mounted horizontally above the boiler. In other cases a separator is attached to the steam-pipe between boilers and engines. This usually consists of an iron tank, divided by a vertical partition extending from the top nearly to the bottom. The steam, entering the top at one side of this partition, passes underneath it, and up to the top on the opposite side, where it issues into a steam-pipe leading directly to the engine. The sudden reversal of its course at the bottom causes it to leave the suspended water in the bottom of the separator, whence it is drained off by pipes.

The most interesting illustrations of recent practice in marine engineering and naval architecture are found in the steamers which are now seen on transoceanic routes for the merchant service, and, in the naval service, in the enormous iron-clads which have been built in Great Britain and the United States.

The City of Peking is one of the finest examples of the older practice. This vessel was constructed for the Pacific Mail Company. The hull is 423 feet long, of 48 feet beam, and 38½ feet deep. Accommodations are furnished for 150 cabin and 1,800 steerage passengers, and the coal-bunkers "stow" 1,500 tons of coal. The iron plates of which the sides and bottom are made are from $\frac{11}{16}$ to one inch in thickness. The weight of iron used in construction was about 5,500,000 pounds. The machinery weighed nearly 2,000,000 pounds, with spare gear and accessory apparatus.

The engines are compound, with two steam-cylinders of 51 inches and two of 88 inches diameter, and a stroke of piston of $4\frac{1}{2}$ feet. The condensing water is sent through the surface-condensers by circulating-pumps driven by their own engines. Ten boilers furnish steam to these engines, each having a diameter of 13 feet, a length of $13\frac{1}{2}$ feet, and a thickness of "shell" of $\frac{13}{16}$ inch. Each has three furnaces, and contains 204 tubes of an outside diameter of $3\frac{1}{4}$ inches. All together, they have 520 square feet of grate-surface and 17,000 square feet of heating-surface. The area of cooling-surface in the condensers is 10,000 square feet. The City of Rome, a ship of later design, is 590 feet long, "over all," 52 feet beam, 52 feet deep, and measures 8,300 tons. The engines, of 8,500 horse-power, will drive the vessel 18 knots (21 miles) an hour; they have six steam-cylinders (three high and three low pressure), and are supplied with steam by 8 boilers heated by 48 furnaces. The hull is of steel, the bottom double, and the whole divided into ten compartments by transverse bulkheads. Two longitudinal bulkheads in the engine and boiler compartments add greatly to the safety of the vessel.

The most successful steam-vessels in general use are these screw-steamers of transoceanic lines. Those of the transatlantic lines are now built from 550 to 650 feet long, generally propelled from 15 to 21 knots (18 to 24 miles) an hour, by engines of from 10,000 to 20,000 horse-power, consuming from 90 to 550 tons of coal a day, and crossing the Atlantic in from 6 to 10 days. These vessels are now invariably fitted with the multiple cylinders and surface-condensers. One of these vessels, the Lucania, has been reported at Sandy Hook, the entrance to New York Harbor, in 5 days 9 hours 27 minutes from Queenstown—a distance, as measured by the log and by observation, of 2,830 miles. Another steamer, the Teutonic, has crossed the Atlantic in 5 days 16 hours and 31 minutes. These vessels are of 13,500 tons burden, of 3,500 "nominal" horse-power (probably 30,000 actual).

The modern steamship is as wonderful an illustration of ingenuity and skill in all interior arrangements as in size,

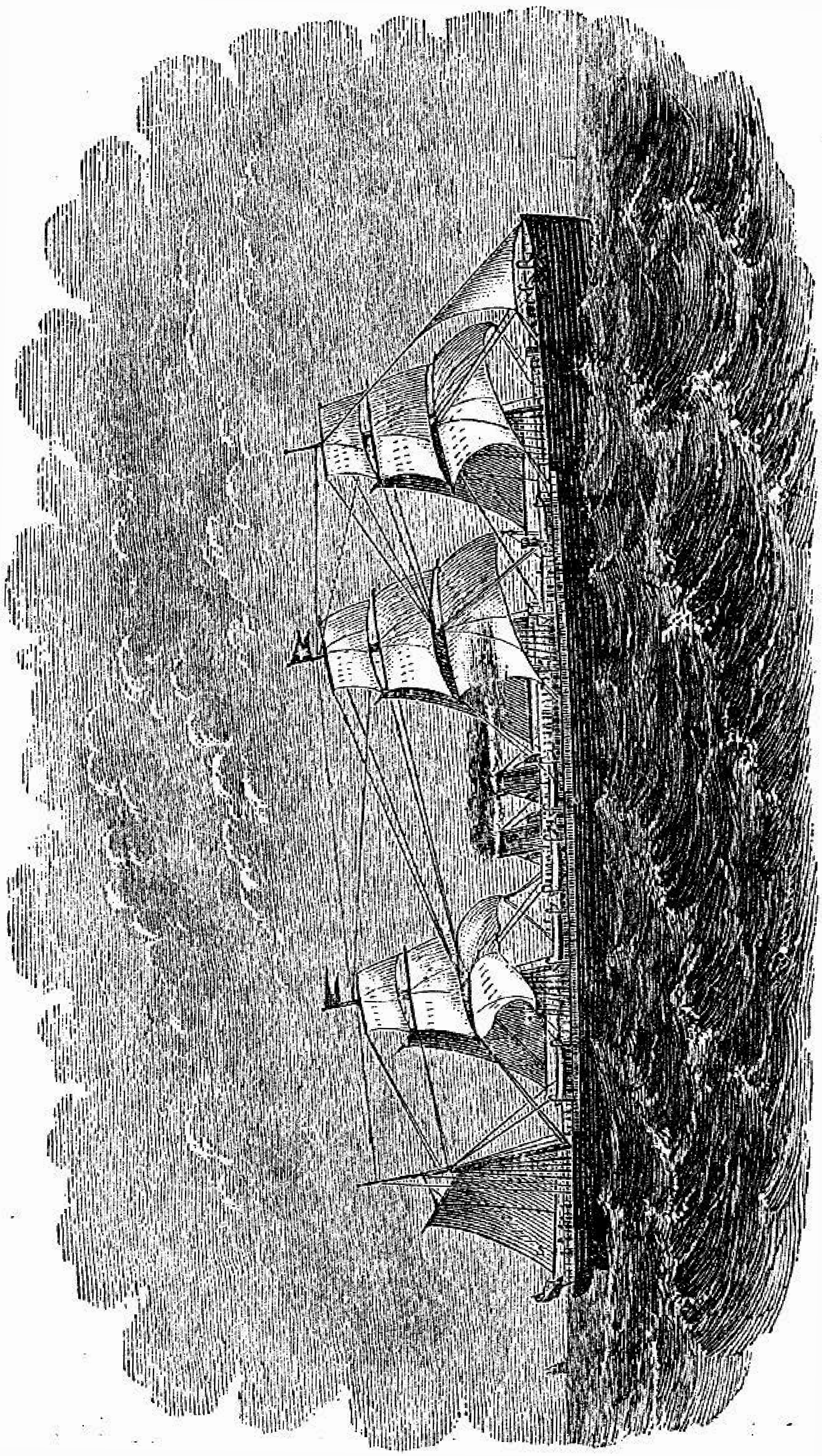


FIG. 144.—The Modern Steamship.

power, and speed. The size of sea-going steamers has become so great that it is unsafe to intrust the raising of the anchor or the steering of the vessel to manual power and skill; and these operations, as well as the loading and unloading of the vessel, are now the work of the same great motor—steam.

The now common form of auxiliary engine for controlling the helm is one of the inventions of the American engineer F. E. Sickels, who devised the "Sickels cut-off," and was first invented about 1850. It was exhibited at London at the International Exhibition of 1851. It consists[1] principally of two cylinders working at right angles upon a shaft geared into a large wheel fastened by a friction-plate lined with wood, and set by a screw to any desired pressure on the steering-apparatus. The wheel turned by the steersman is connected with the valve-gear of the cylinders, so that the steam, or other motor, will move the rudder precisely as the helmsman moves the wheel adjusting the steam-valves. This wheel thus becomes the steering-wheel. The apparatus is usually so arranged that it may be connected or disconnected in an instant, and hand-steering adopted if the smoothness of the sea and the low speed of the vessel make it desirable or convenient. This method was first adopted in the United States on the steamship Augusta.

The same inventor and others have contrived "steam-windlasses," some of which are in general use on large vessels. The machinery of these vessels is also often fitted with a steam "reversing-gear," by means of which the engines are as easily manœuvred as are those of the smallest vessels, to which hand-gear is always fitted. In one of these little auxiliary engines, as devised by the author, a small handle being adjusted to a marked position, as to the point marked "stop," on an index-plate, the auxiliary engine at once starts, throws the valve-gear into the proper position—

[1] "Official Catalogue," 1862, vol. iv., Class viii., p. 123.

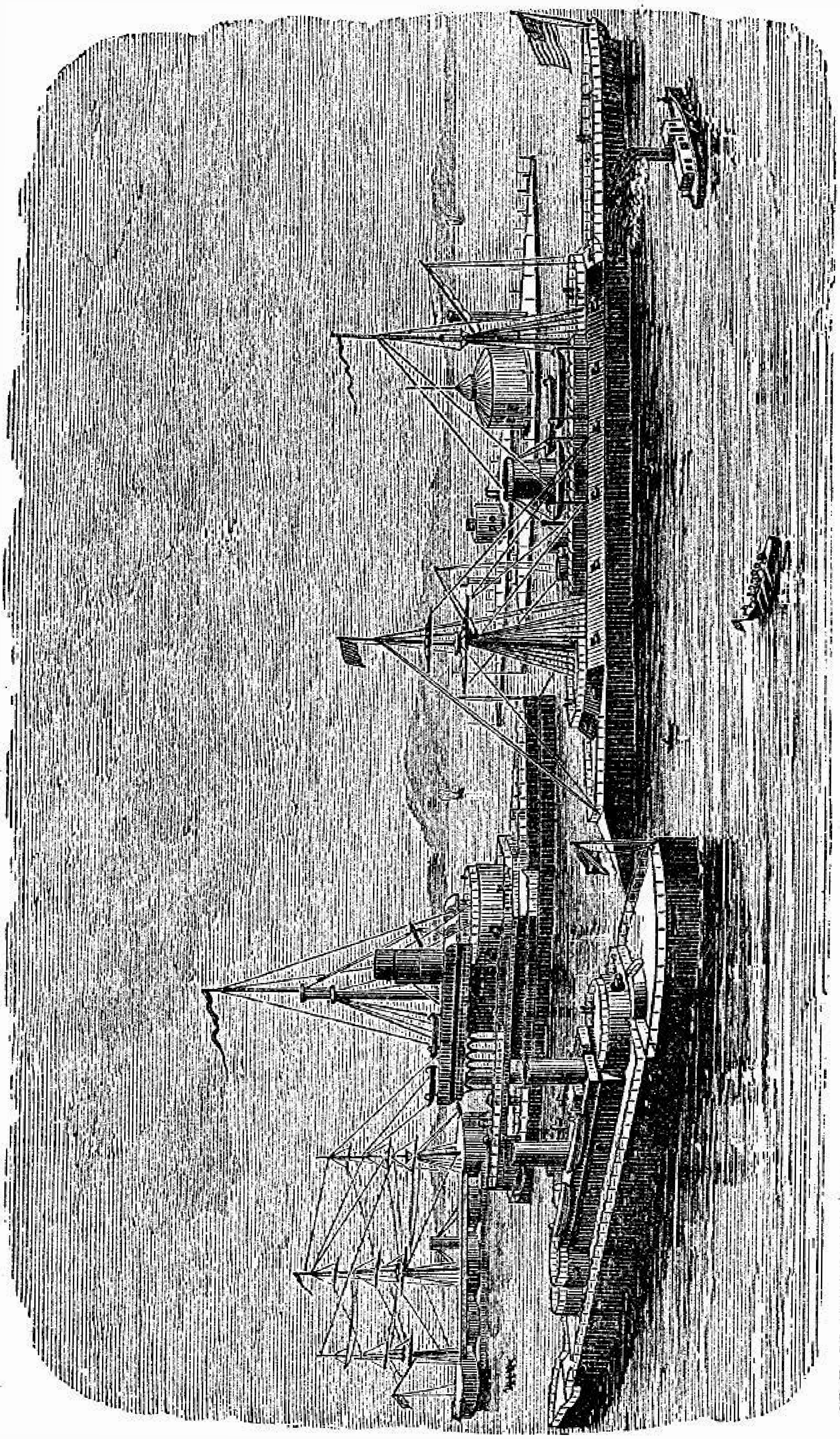
as, if a link-motion, into "middle-gear"—thus stopping the large engines, and then it itself stops. Setting the handle so that its pointer shall point to "ahead," the little engine starts again, sets the link in position to go ahead, thus starting the large engines, and again stops itself. If set at "back," the same series of operations occurs, leaving the main engines backing and the little "reversing engine" stopped. A number of forms of reversing engine are in use, each adapted to some one type of engine.

The hull of the transatlantic steamer is now always of iron, and is divided into a number of "compartments," each of which is water-tight and separated from the adjacent compartments by iron "bulkheads," in which are fitted doors which, when closed, arenalso water-tight. In some cases these doors close automatically when the water rises in the vessel, thus confining it to the leaking portion.

Thus we have already seen a change in transoceanic lines from steamers like the Great Western (1837), 212 feet in length, of $35\frac{1}{2}$ feet beam, and 23 feet depth, driven by engines of 450 horse-power, and requiring 15 days to cross the Atlantic, to steamships over 600 feet long, 65 feet beam, and 55 feet deep, with engines of 20,000 horse-power, crossing the Atlantic in $5\frac{1}{2}$ days; iron substituted for wood in construction, the cost of fuel reduced one-half, and the speed raised from 8 to 20 knots and over. In the earlier days of steamships they were given a proportion of length to breadth of from 5 to 6 to 1; in forty years the proportion increased until 10 to 1 was reached.

The whole naval establishment of every country has been greatly modified by the recent changes in methods of attack and defense; but the several classes ofnships which still form the naval marine are all as dependent upon their steam-machinery as ever.

It is only recently that the attempt seems to have been made to determine a classification of war-vessels and to plan a naval establishment which shall benlikely to meet fully the requirements of the immediate future. It has hitherto been customary simply to make each ship a little stronger, faster, or more powerful to resist or to make



H. B. M. Iron-Clad Captain. H. B. M. Iron-Clad Thunderer. U. S. Iron-Clad Dictator. U. S. Iron-Clad Monitor.
H. B. M. Iron-Clad Glatton. French Iron-Clad Dunderberg.

FIG. 145.—Modern Iron-Clads.

attack than was the last. The fact that the direction of progress in naval science and architecture is plainly perceivable, and thatnupon its study may be based a fair estimate of the character and relative distribution of several classes of vessels, seems to have been appreciated by very few.

In the year 1870 the writer proposed[1] a classification of vessels other than torpedo-vessels, which has since been also proposed in a somewhat modified form by Mr. J. Scott Russell.[2] The author then remarked that the increase so rapidly occurring in weight of ordnance and of armor, and in speed of war-vessels, would probably soon compel a division of the vessels of every navy into three classes of ships, exclusive of torpedo-vessels, one for general service in time of peace, the others for use only in time of war.

"The first class may consist of unarmored vessels of moderate size, fair speed under steam, armed with a few tolerably heavy guns, and carrying full sail-power.

"The second class may be vessels of great speed under steam, unarmored, carrying light batteries and as great spread of canvas as can readily be given them; very much such vessels as the Wampanoag class of our own navy were intended to be—calculated expressly to destroy the commerce of an enemy.

"The third class may consist of ships carrying the heaviest possible armor and armament, with strongly-built bows, the most powerful machinery that can be given them, of large coal-carrying capacity, and unencumbered by sails, everything being made secondary to the one object of obtaining victory in contending with the most powerful of possible opponents. Such vessels could never go to sea singly, but would cruise in couples or in squadrons. It seems hardly doubtful that attempts to combine the qualities of all classes in a single vessel, as has hitherto been

[1] *Journal Franklin Institute*, 1870. H. B. M. S. Monarch.

[2] London *Engineering*, 1875.

done, will be necessarily given up, although the classification indicated will certainly tend largely to restrict naval operations."

The introduction of the stationary, the floating, and the automatic classes of torpedoes, and of torpedo-vessels, has now become accomplished, and this element, which it was predicted by Bushnell and by Fulton three-quarters of a century ago would at some future time become important in warfare, is now well recognized by all nations. How far it may modify future naval establishments cannot be yet confidently stated, but it seems sufficiently evident that the attack, by any navy, of stationary defenses protected by torpedoes is now quite a thing of the past. It may be perhaps looked upon as exceedingly probable that torpedo-ships of very high speed will yet drive all heavily-armored vessels from the ocean, thus completing the historic parallel between the man-in-armor of the middle ages and the armored man-of-war of our own time.[1]

Of these classes, the third is of most interest, as exhibiting most perfectly the importance and variety of the work which the steam-engine is made to perform. On the later of these vessels, the anchor is raised by a steam anchor-hoisting apparatus; the heavier spars and sails are handled by the aid of a steam-windlass; the helm is controlled by a steering-engine, and the helmsman, with his little finger, sets in motion a steam-engine, which adjusts the rudder with a power which is unimpeded by wind or sea, and with an exactness that could not be exceeded by the hand-steering gear of a yacht; the guns are loaded by steam, are elevated or depressed, and are given lateral training, by the same power; the turrets in which the guns are incased are turned, and the guns are whirled toward every point of the compass, in less time than is required to sponge and reload

[1] *Vide* "Report on Machinery and Manufactures, etc., at Vienna," by the author, Washington, 1875.

them; and the ship itself is driven through the water by the power of ten thousand horses, at a speed which is only excelled on land by that of the railroad-train.

The British Minotaur was one of the earlier iron-clads. The great length and consequent difficulty of manœuvring, the defect of speed, and the weakness of armor of these vessels have led to the substitution of far more effective designs in later constructions. The Minotaur is a four-masted screw iron-clad, 400 feet long, of 59 feet beam and 26½ feet draught of water. Her speed at sea is about 12½ knots, and her engines develop, as a maximum, nearly 6,000 indicated horse-power. Her heaviest armor-plates are but 6 inches in thickness. Her extreme length and her unbalanced rudder make it difficult to turn rapidly. With *eighteen men at the steering-wheel* and sixty others on the tackle, the ship, on one occasion, was 7½ minutes in turning completely around. These long iron-clads were succeeded by the shorter vessels designed by Mr. E. J. Reed, of which the first, the Bellerophon, was of 4,246 tons burden, 300 feet long by 56 feet beam, and 24½ feet draught, of the 14-knot speed, with 4,600 horse-power; and having the "balanced rudder" used many years earlier in the United States by Robert L. Stevens,[1] it can turn in four minutes with eight men at the wheel. The cost of construction was some $600,000 less than that of the Minotaur. A still later vessel, the Monarch, was constructed on a system quite similar to that known in the United States as the Monitor type, or as a turreted iron-clad. This vessel is 330 feet long, 57½ feet wide, and 36 feet deep, drawing 24½ feet of water. The total weight of ship and contents is over 8,000 tons, and the engines are of over 8,500 horse-power. The armor is 6 and 7 inches thick on the hull, and 8 inches on the two turrets, over a heavy teak backing. The turrets contain each two 12-inch rified guns, weighing 25 tons each, and,

[1] Still in use on the Hoboken ferry-boats.

with a charge of 70 pounds of powder, throwing a shot of 600 pounds weight with a velocity of 1,200 feet per second, and giving it a *vis viva* equivalent to the raising of over 6,100 tons one foot high, and equal to the work of penetrating an iron plate 13½ inches thick. This immense vessel is driven by a pair of "single-cylinder" engines having steam-cylinders *ten feet* in diameter and of 4½ feet stroke of piston, driving a two-bladed Griffith screw of 23½ feet diameter and 26½ feet pitch, 65 revolutions, at the maximum speed of 14.9 knots, or about 17½ miles, an hour. To drive these powerful engines, boilers having an aggregate of about 25,000 square feet (or more than a half-acre) of heating-surface are required, with 900 square feet of grate-surface. The refrigerating surface in the condensers has an area of 16,500 square feet—over one-third of an acre. The cost of these engines and boilers was £66,500.

Were all this vast steam-power developed, giving the vessel a speed of 15 knots, the ship, if used as a "ram," would strike an enemy at rest with the tremendous "energy" of 48,000 foot-tons—equal to the shock of the projectiles of eight or nine such guns as are carried by the iron-clad itself, simultaneously discharged upon one spot.

But even this great vessel is less formidable than later vessels. One of the latter, U. S. S. Indiana, is a longer, wider and deeper ship than the Monarch, measuring 420 feet long, 75 feet beam, and 25 draught, displacing over 11,500 tons. The great rifles carried by this vessel weigh 60 tons each, throwing shot weighing a half-ton from behind iron plating 1½ feet in thickness. The steam-engines are of about twice the power of those of the Monarch, and give this enormous hull a speed of 16 knots an hour.

The navy of the United States does not to-day possess a fleet of power even approximating that of either of several classes of several other foreign powers.

The largest vessel of any class yet constructed is the Great Eastern (Fig. 146), begun in 1854 and completed in

1859, by J. Scott Russell, on the Thames, England. This ship is 680 feet long, 83 feet wide, 58 feet deep, 28 feet draught, and of 24,000 tons measurement. There are four paddle and four screw engines, the former having steam-cylinders 74 inches in diameter, with 14 feet stroke, the latter 84 inches in

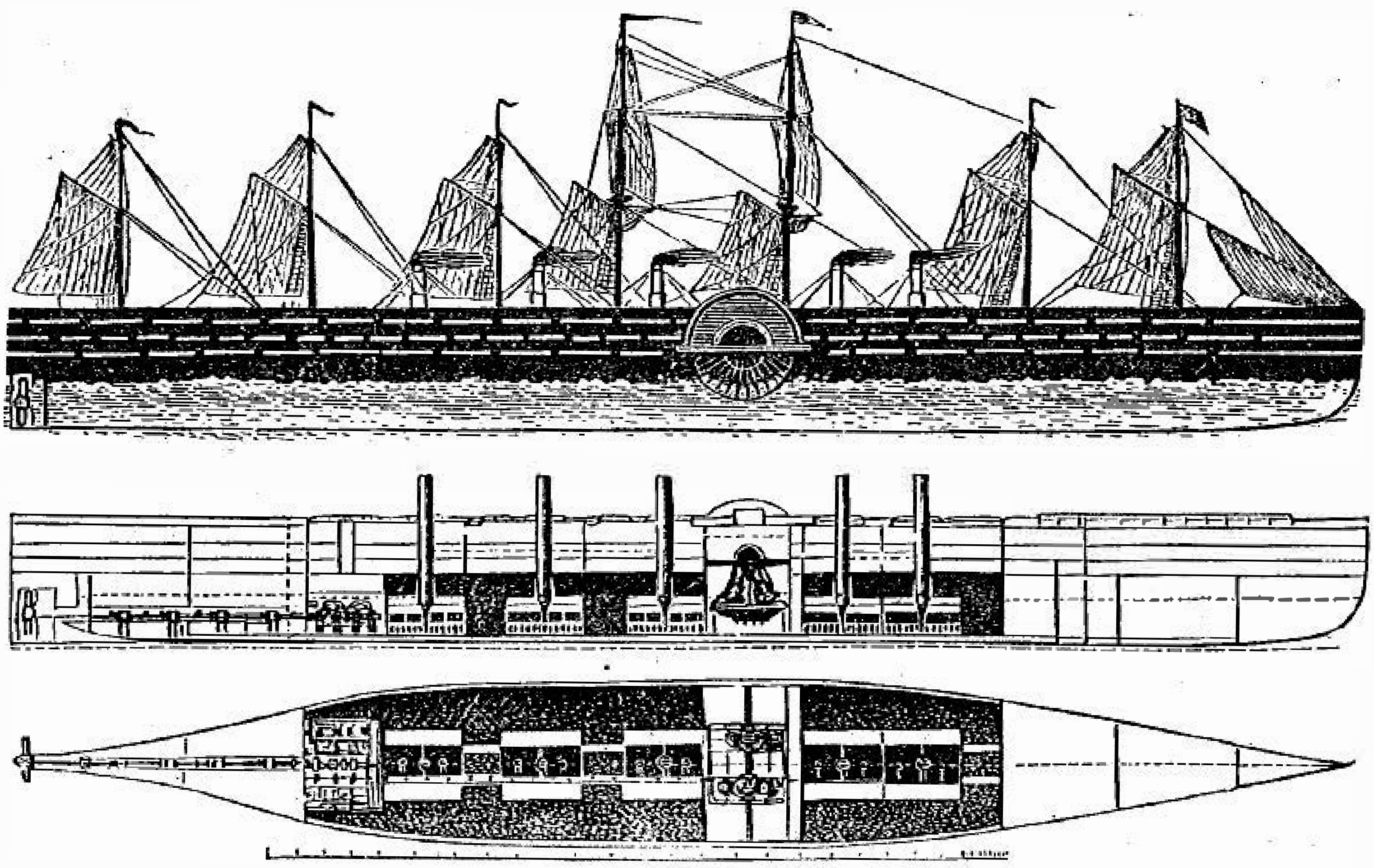


FIG. 146.—The Great Eastern.

diameter and 4 feet stroke. They are collectively of 10,000 actual horse-power. The paddle-wheels are 56 feet in diameter, the screw 24 feet. The steam-boilers supplying the paddle-engines have 44,000 square feet (more than an acre) of heating-surface. The boilersnsupplying the screw-engines are still larger. At 30 feet draught, this great vessel displaces 27,000 tons.n The engines were designed to develop 10,000 horse-power, driving the ship at the rate of $16\frac{1}{2}$ statute miles an hour.

The figures quoted in the descriptions of these great steamships do not enable the non-professional reader to form a conception of the wonderful power which is concentrated within so small a space as is occupied by their steam-machinery. The "horse-power" of the engines is that determined by James Watt as the maximum obtainable for eight hours a day from the strongest London draught-horses. The ordinary average draught-horse would hardly be able to exert two-thirds as much during the eight hours' steady work of a working-day. The working-day of the steam-engine, on the other hand, is twenty-four hours in length.

The work of the 30,000 horse-power engines of the Lucania could be barely equaled by the efforts of 40,000 horses; but to continue their work uninterruptedly, day

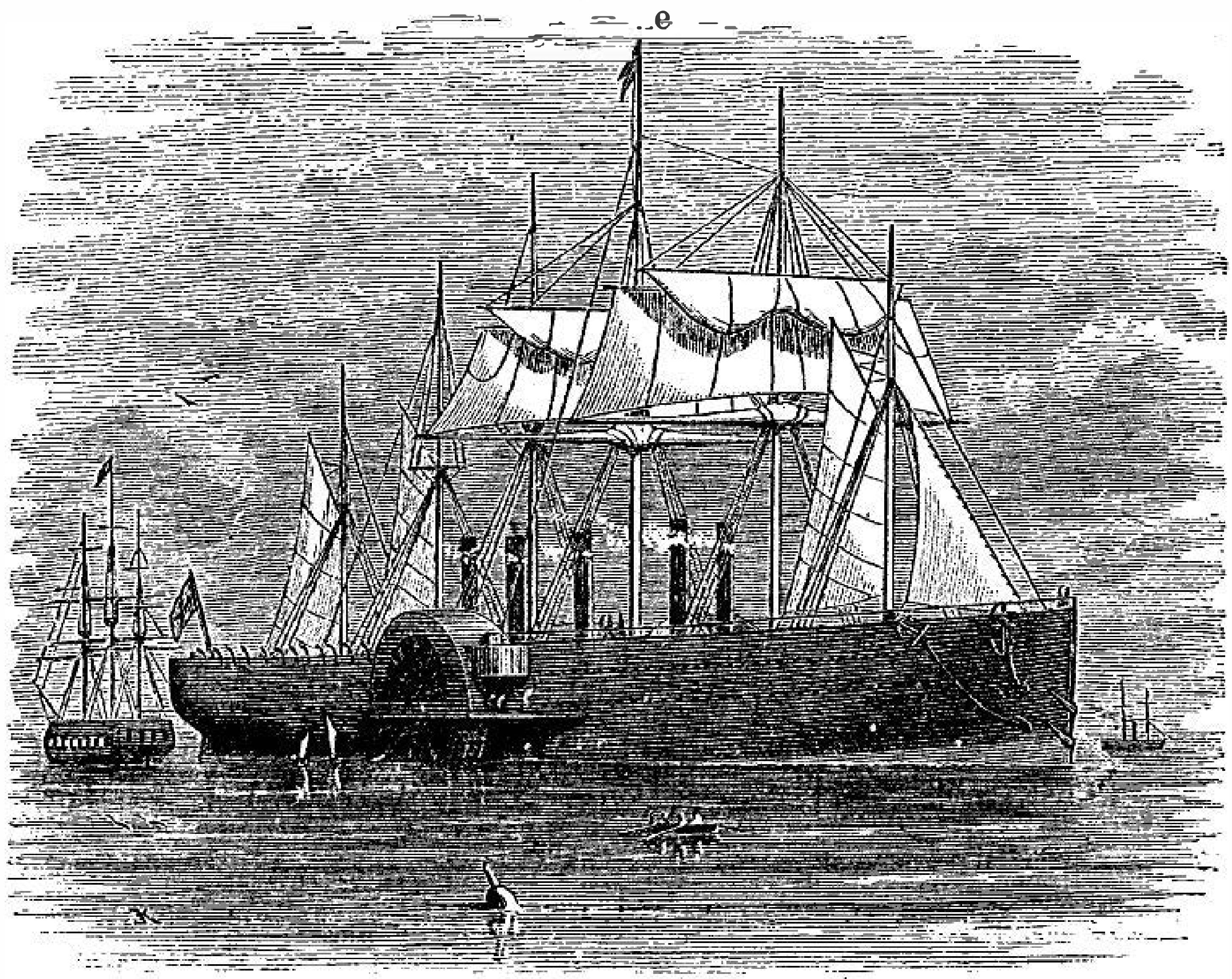


FIG. 147.—The Great Eastern at Sea.

in and day out, for weeks together, as when done by steam, would require at least three relays—120,000 horses. Such a stud would weigh 60,000 tons, and if harnessed "tandem" would extend ninety miles. It is only by such a comparison that the mind can begin to comprehend the utter impossibility of accomplishing by means of animal power the work now done for the world by steam. The cost of the greater power is but about one-tenth that of horse-power, and by its means tasks are accomplished with ease which are absolutely impossible of accomplishment by animal power.

It is estimated that the total steam-power of the world is about 90,000,000 horse-power, and that, were horses actually employed to do the work which these engines would be capable of doing were they kept constantly in operation, the number required would exceed 150,000,000.

Thus, from the small beginnings of the Comte d'Auxiron and the Marquis de Jouffroy in France, of Symmington in Great Britain, and of Henry, Rumsey, and Fitch, and of Fulton and Stevens, in the United States, steam-navigation has grown into a great and inestimable aid and blessing to mankind.

We to-day cross the ocean with less risk, and transport ourselves and our goods at as little cost in either time or money as, at the beginning of the century, our parents experienced in traveling one-tenth the distance.

It is largely in consequence of this ingenious application of a power that reminds one of the fabled genii of Eastern romance, that the mechanic and the laborer of to-day enjoy comforts and luxuries that were denied to wealth, and to royalty itself, a century ago.

The magnitude of our modern steamships excites the wonder and admiration of even the people of our own time; and there is certainly no creation of art that can be grander in appearance than a transatlantic steamer a hundred and fifty yards in length, and weighing, with her stores, five or six thousand tons, as she starts on her voyage, moved by engines equal in power to the united strength of thousands of horses; none can more fully awaken a feeling of awe than an immense structure like the great modern iron-clads (Fig. 145), vessels having a total weight of 10,000 to 15,000 tons, and propelled by steam-engines of as many horse-power, carrying guns whose shot penetrate solid iron 30 inches thick, and having a power of impact, when steaming at moderate speed, sufficient to raise 100,000 tons a foot high.

Thus we are to-day witnessing the literal fulfillment of the predictions of Oliver Evans and of John Stevens, and almost that contained in the couplets written by the poet Darwin, who, more than a century ago, before even the earliest of Watt's improvements had become generally known, sang:

> "Soon shall thy arm, unconquered Steam, afar
> Drag the slow barge, or drive the rapid car;
> Or, on wide-waving wings expanded, bear
> The flying chariot through the fields of air."